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AN
ELEMENTARY COURSE
OF
CIVIL ENGINEERING,

FOR THE USE OF

CADETS OF THE UNITED STATES' MILITARY ACADEMY

BY

D. H. MAHAN, M. A.,

PROFESSOR OF MILITARY AND CIVIL ENGINEERING IN THE
MILITARY ACADEMY.

SIXTH EDITION,
WITH LARGE ADDENDA AND MANY NEW CUTS.

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PREFACE.

The present Edition of this Work, like the two preceding, has been compiled for the use of the cadets of the U. S. Military Academy, and comprises that part of the Course of Civil Engineering taught them which the Author deemed would prove the most useful to pupils in other seminaries, studying for the profession of the civil engineer.

In preparing this Edition, the Author has found it necessary to recast and rewrite the greater portion of the work; owing to the considerable additions made to it, and called for by the vast accumulation of important facts since the publication of the former editions. A new form has also been given to the work, in the substitution of wood-cuts in the body of it for the plates in the former editions, as better adapted to its main object as a text-book. From these additions and changes, the Author trusts that the work will be found to contain all of the essential

principles and facts respecting those branches of the subject of which it treats; and that it will prove a serviceable aid to instructors and pupils, in opening the way to a more extensive prosecution of the studies connected with the engineer's art.

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ELEMENTARY COURSE

OF

CIVIL ENGINEERING.

BUILDING MATERIALS.

1. A KNOWLEDGE of the properties of building materials is one of the most important branches of Civil Engineering. An engineer, to be enabled to make a judicious selection of materials, and to apply them so that the ends of sound economy and skilful workmanship shall be equally subserved, must know their ordinary durability under the various circumstances in which they are employed, and the means of increasing it when desirable; their capacity to sustain, without injury to their physical qualities, permanent strains, whether exerted to crush them, tear them asunder, or to break them transversely; their resistance to rupture and wear, from percussion and attrition; and, finally, the time and expense necessary to convert them to the uses for which they may be required.

2. The materials in general use for civil constructions may be arranged under the three following heads:

1st. Those which constitute the more solid components of structures, as *Stone*, *Brick*, *Wood*, and the *Metals*.

2d. The cements in general, as *Mortar*, *Mastics*, *Glue*, &c., which are used to unite the more solid parts.

3d. The various mixtures and chemical preparations, as solutions of *Salts*, *Paints*, *Bituminous Substances*, &c., employed to coat the more solid parts, and protect them from the chemical and mechanical action of atmospheric changes, and other causes of destructibility.

STONE.

3 The term *Stone*, or *Rock*, is applied to any aggregation of several mineral substances. Stones, for the convenience of description, may be arranged under three general heads—the *silicious*, the *argillaceous*, and the *calcareous*.

4. Silicious Stones. The stones arranged under this head receive their appellation from *silex*, the principal constituent of the minerals which compose them. They are also frequently designated, either according to the mineral found most abundantly in them, or from the appearance of the stone, as *feldspathic*, *quartzose*, *arenaceous*, &c.

5. The silicious stones generally do not effervesce with acids, and emit sparks when struck with a steel. They possess, in a high degree, the properties of strength, hardness, and durability; and, although presenting great diversity in the degree of these properties, as well as in their structure, they furnish an extensive variety of the best stone for the various purposes of the engineer and architect.

6. *Sienite*, *Porphyry*, and *Green-stone*, from the abundance of feldspar which they contain, are often designated as feldspathic rocks. For durability, strength, and hardness, they may be placed in the first rank of silicious stones.

7. *Sienite* consists of a granular aggregation of feldspar, hornblende, and quartz. It furnishes one of the most valuable building stones, particularly for structures which require great strength, or are exposed to any very active causes of destructibility, as sea walls, lighthouses, and fortifications. Sienite occurs in extensive beds, and may be obtained, from the localities where it is quarried, in blocks of any requisite size. It does not yield easily to the chisel, owing to its great hardness, and when coarse-grained it cannot be wrought to a smooth surface. Like all stones in which feldspar is found, the durability of sienite depends essentially upon the composition of this mineral, which, owing to the potash it contains, sometimes decomposes very rapidly when exposed to the weather. The durability of feldspathic rocks, however, is very variable, even where their composition is the same; no pains should therefore be spared to ascertain this property in stone taken from new quarries, before using it for important public works.

8. *Porphyry*. This stone is usually composed of compact feldspar, having crystals of the same, and sometimes those of other minerals, scattered through the mass. Porphyry furnishes stones of various colors and texture; the usual color being reddish, approaching to purple, from which the stone takes its name. One of the most beautiful varieties is a *brecciated* porphyry, consisting of angular fragments of the stone united by a cement of compact feldspar. Porphyry, from its rareness and extreme hardness, is seldom applied to any other than ornamental purposes. The best known localities of sienite and porphyry are in the neighborhood of Boston.

9. *Green-stone*. This stone is a mixture of hornblende with

common and compact feldspar, presenting sometimes a granular though usually a compact texture. Its ordinary color, when dry is some shade of brown; but, when wet, it becomes greenish, from which it takes its name. Green-stone is very hard, and one of the most durable rocks; but, occurring in small and irregular blocks, its uses as a building stone are very restricted When walls of this stone are built with very white mortar, they present a picturesque appearance, and it is on that account well adapted to rural architecture. Green-stone might also be used as a material for road-making; large quantities of it are annually taken from the principal locality of this rock in the United States, so well known as the Palisades, on the Hudson, for constructing wharves, as it is found to withstand well the action of salt water.

10. *Granite* and *Gneiss*. The constituents of these two stones are the same; being a granular aggregation of quartz, feldspar, and mica, in variable proportions. They differ only in their structure; gneiss being a stratified rock, the ingredients of which occur frequently in a more or less laminated state. Gneiss, although less valuable than granite, owing to the effect of its structure on the size of the blocks which it yields, and from its not splitting as smoothly as granite across its beds of stratification, furnishes a building stone suitable for most architectural purposes. It is also a good flagging material, when it can be obtained in thin slabs.

Granite varies greatly in quality, according to its texture and the relative proportions of its constituents. When the quartz is in excess, it renders the stone hard and brittle, and very difficult to be worked with the chisel. An excess of mica usually makes the stone friable. An excess of feldspar gives the stone a white hue, and makes it freer under the chisel. The best granites are those with a fine grain, in which the constituents seem uniformly disseminated through the mass. The color of granite is usually some shade of gray; when it varies from this, it is owing to the color of the feldspar. One of its varieties, known as *Oriental* granite, has a fine reddish hue, and is chiefly used for ornamental purposes. Granite is sometimes mistaken for sienite, when it contains but little mica.

The quality of granite is affected by the foreign minerals which it may contain; hornblende is said to render it tough, and schorl makes it quite brittle. The protoxide and sulphurets of iron are the most injurious in their effects on granite; the former by conversion into a peroxide, and the latter by decomposing, destroying the structure of the stone, and causing it to break up and disintegrate.

Granite, gneiss, and sienite, differ so little in their essential

qualities, as a building material, that they may be used indiffer ently for all structures of a solid and durable character. They are extensively quarried in most of the New England States, in New York, and in some of the other States intersected by the great range of primitive rocks, where the quarries lie contiguous to tide-water.

11. *Mica Slate.* The constituents of this stone are quartz and mica; the latter predominating. It is principally used as a *flag ging* stone, and as a *fire* stone, or lining for furnaces.

12. *Buhr*, or *Mill-stone.* This is a very hard, durable stone, presenting a peculiar, honeycomb appearance. It makes a good building material for common purposes, and is also suitable for road coverings.

13. *Horn-stone.* This is a highly silicious and very hard stone. It resembles flint in its structure, and takes its name from its translucent, horn-like appearance. It furnishes a very good road material.

14. *Steatite*, or *Soap-stone.* This stone is a partially indurated talc. It is a very soft stone, and not suitable for ordinary building purposes. It furnishes a good fire-stone, and is used for the lining of fireplaces.

15. *Talcose Slate.* This stone resembles mica slate, being an aggregation of quartz and talc. It is applied to the same purposes as mica slate.

16. *Sand-stone.* This stone consists of grains of silicious sand, arising from the disintegration of silicious rocks, which are united by some natural cement, generally of an argillaceous or a silicious character.

The strength, hardness, and durability of sand-stone vary between very wide limits. Some varieties being little inferior to good granite, as a building stone, others being very soft, friable, and disintegrating rapidly when exposed to the weather. The least durable sand-stones are those which contain the most argillaceous matter; those of a feldspathic character are also found not to withstand well the action of weather.

Sand-stone is used very extensively as a building stone, for flagging, for road materials, and some of its varieties furnish an excellent fire-stone. Most of the varieties of sand-stone yield readily under the chisel and saw, and split evenly, and, from these properties, have received from workmen the name of *free stone*. The colors of sand-stone present also a variety of shades, principally of gray, brown, and red.

The formations of sand-stone in the United States are very extensive, and a number of quarries are worked in New England, New York, and the Middle States. These formations, and the character of the stone obtained from them, are minutely described

in the *Geological Reports of these States,* which have been published within the last few years.

Most of the stone used for the public buildings in Washington, is a sand-stone obtained from quarries on Acquia Creek and the Rappahannock. Much of this stone is feldspathic, possesses but little strength, and disintegrates rapidly. The red sand-stones which are used in our large cities, are either from quarries in a formation extending from the Hudson to North Carolina, or from a separate deposite in the valley of the Connecticut. The most durable and hard portions of these formations occur in the neighborhood of trap dikes. The fine flagging-stone used in our cities is mostly obtained, either from the Connecticut quarries, or from others near the Hudson, in the Catskill group of mountains. Many quarries, which yield an excellent building stone, are worked in the extensive formations along the Appalachian range, which extends through the interior, through New York and Virginia, and the intermediate States.

17. Argillaceous Stones. The stones arranged under this head are mostly composed of clay, in a more or less indurated state, and presenting a laminated structure. They vary greatly in strength, and are generally not durable, decomposing in some cases very rapidly, from changes in the metallic sulphurets and salts found in most of them. The uses of this class of stones are restricted to roofing and flagging.

18. *Roofing Slate.* This well-known stone is obtained from a hard, indurated clay, the surfaces of the lamina having a natural polish. The best kinds split into thin, uniform, light slabs; are free from sulphurets of iron; give a clear ringing sound when struck; and absorb but little water. Much of the roofing slate quarried in the United States is of a very inferior quality, and becomes rotten, or decomposes, after a few years' exposure. The durability of the best European slate is about one hundred years; and it is stated that the material obtained from some of the quarries worked in the United States, is not apparently inferior to the best foreign slate brought into our markets. Several quarries of roofing slate are worked in the New England States, New York, and Pennsylvania.

19. *Graywacke Slate.* The composition of this stone is mostly indurated clay. It has a more earthy appearance than argillaceous slate, and is generally distinctly arenaceous. Its colors are usually dark gray, or red. It is quarried principally for flagging-stone.

20. *Hornblende Slate* This stone, known also as green-stone slate, properly belongs to the silicious class. It consists mostly of hornblende having a laminated structure. It is chiefly quarried for flagging-stone.

21. CALCAREOUS STONES. Lime is the principal constituent of this class, the carbonates of which, known as *lime-stone* and *marble*, furnish a large amount of ordinary building stone, most of the ornamental stones, and the chief ingredient in the composition of the cements and mortars, used in stone and brick-work. Lime-stone effervesces copiously with acids; its texture is destroyed by a strong heat, which also drives off its carbonic acid and water, converting it into *quick* lime. By absorbing water, quick-lime is converted into a *hydrate*, or *slaked* lime; considerable heat is evolved during this chemical change, and the stone increases in bulk, and gradually crumbles down into a fine powder.

The lime-stones present great diversity in their physical properties. Some of them seem as durable as the best silicious stones, and are but little inferior to them in strength and hardness; others decompose rapidly on exposure to the weather; and some kinds are so soft that, when first quarried, they can be scratched with the nail, and broken between the fingers. The lime-stones are generally impure carbonates; and we are indebted to these impurities for some of the most beautiful, as well as the most invaluable materials used for constructions. Those which are colored by metallic oxides, or by the presence of other minerals, furnish the large number of colored and variegated marbles; while those which contain a certain proportion of clay, or of magnesia, yield, on calcination, those cements which, from their possessing the property of hardening under water, have received the various appellations of *hydraulic* lime, *water* lime, *Roman* cement, &c.

Lime-stone is divided into two principal classes, *granular* lime-stone and *compact* lime-stone. Each of these furnishes both the marbles and ordinary building stone. The varieties not susceptible of receiving a polish, are sometimes called *common* lime-stone.

The granular lime-stones are generally superior to the compact for building purposes. Those which have the finest grain are the best, both for marbles and ordinary building stone. The coarse-grained varieties are frequently friable, and disintegrate rapidly when exposed to the weather. All the varieties, both of the compact and granular, work freely under the chisel and grit-saw, and may be obtained in blocks of any suitable dimensions for the heaviest structures.

The durability of lime-stone is very materially affected by the foreign minerals it may contain; the presence of clay injures the stone, particularly when, as sometimes happens, it runs through the bed in very minute veins: blocks of stone having this imperfection, soon separate along these veins on exposure to moisture. The protoxide, the protocarbonate, and the sulphuret of iron, are

also very destructive in their effects; frequently causing by their chemical changes, rapid disintegration.

Among the varieties of impure carbonates of lime, the *magnesian* lime-stones, called *dolomites*, merit to be particularly noticed. They are regarded in Europe as a superior building material; those being considered the best which are most crystalline, and are composed of nearly equal proportions of the carbonates of lime and magnesia. Some of the quarries of this stone, which have been opened in New York and Massachusetts, have given a different result; the stone obtained from them being, in some cases, extremely friable.

22. *Marbles*. The term marble is now applied exclusively to any lime-stone which will receive a polish. Owing to the cost of preparing marble, it is restricted in its uses to ornamental purposes. The marbles present great variety, both in color and appearance, and have generally received some appropriate name descriptive of these accidents.

23. *Statuary Marble* is of the purest white, finest grain, and free from all foreign minerals. It receives that delicate polish, without glare, which admirably adapts it to the purposes of the sculptor, for whose uses it is mostly reserved.

24. *Conglomerate Marble*. This consists of two varieties; the one termed *pudding* stone, which is composed of rounded pebbles imbedded in compact lime-stone; the other termed *breccia*, consisting of angular fragments united in a similar manner. The colors of these marbles are generally variegated, forming a very handsome ornamental material.

25. *Birds-eye Marble*. The name of this stone is descriptive of its appearance, which arises from the cross sections of a peculiar fossil (*fucoides demissus*) contained in the mass, made in sawing or splitting it.

26. *Lumachella Marble*. This is obtained from a lime-stone having shells imbedded in it, and takes its name from this circumstance.

27. *Verd Antique*. This is a rare and costly variety, of a beautiful green color, caused by veins and blotches of *serpentine* diffused through the lime-stone.

28. The terms *veined*, *golden*, *Italian*, *Irish*, &c., given to the marbles found in our markets, are significant of their appearance, or of the localities from which they are procured.

29. Lime-stone is so extensively diffused throughout the United States, and is quarried, either for building stone or to furnish lime, in so many localities, that it would be impracticable to enumerate all within any moderate compass. One of the most remarkable formations of this stone extends, in an uninterrupted bed, from Canada, through the States of Vermont, Mass., Conn.

New York, New Jersey, Penn., and Virg., and, in all probability much farther south.

Marbles are quarried in various localities in the United States Among the most noted are the quarries in Berkshire Co., Mass., which furnish both pure and variegated marbles; those on the Potomac, from which the columns of conglomerate marbles were obtained that are seen in the interior of the Capitol at Washington; several in New York, which furnish white, the birds-eye, and other variegated kinds; and some in Conn., which, among other varieties, furnish a verd antique of handsome quality.

Lime-stone is burned, either for building or agricultural purposes, in almost every locality where deposites of the stone occur. Thomaston, in Maine, has supplied for some years most of the markets on the sea-board with a material which is considered as a superior article for ordinary building purposes. One of the greatest additions to the building resources of our country, was made in the discovery of the hydraulic or water lime-stones of New York. The preparation of this material, so indispensable for all hydraulic works and heavy structures of stone, is carried on extensively at Roundout, on the Delaware and Hudson canal, in Madison Co., and is sent to every part of the United States, being in great demand for all the public works carried on under the superintendence of our civil and military engineers. A not less valuable addition to our building materials has been made by Prof. W. B. Rogers, who, a few years since, directed the attention of engineers to the dolomites, for their good hydraulic properties. From experiments made by Vicat, in France, who first there observed the same properties in the dolomite, and from those in our own country, it appears highly probable that the magnesian lime-stones, containing a certain proportion of magnesia, will be found fully equal to the argillaceous, from which hydraulic lime has hitherto been solely obtained.

Both of these lime-stones belong to very extensive formations. The hydraulic lime-stones of New York occur in a déposite called the Water-lime Group, in the Geological Survey of New York corresponding to formation VI. of Prof. H. B. Rogers' arrangement of the rocks of Penn. This formation is co-extensive with the Helderberg Range as it crosses New York; it is exposed in many of the valleys of Penn. and Virg., west of the Great Valley. It may be sought for just below or not far beneath the Oriskany sand-stones of the New York Survey, which correspond to formation VII. of Rogers. This sand-stone is easily recognised, being of a yellowish white color, granular texture, with large cavities left by decayed shells. The lime-stone is usually an earthy drab-colored rock, sometimes a greenish blue, which does no slake after being burned.

The hydraulic magnesian lime-stones belong to the formations II. and VI. of Rogers; the first of these is the same as the Black River, or Mohawk lime-stone of the New York Survey. It is the oldest fossiliferous lime-stone in the United States, and occurs throughout the whole bed, associated with the slates which occupy formation III. of Rogers, and are called the Hudson River Group in the New-York Survey. This extensive bed lies in the great Appalachian Valley, known as the Valley of Lake Champlain, Valley of the Hudson, as far as the Highlands, Cumberland Valley, Valley of Virginia, and Valley of East Tennessee. The same stone is found in the deposites of some of the western valleys of the mountain region of Penn. and Virginia.

The importance of hydraulic lime to the security of structures exposed to constant moisture, renders a knowledge of the geological positions of those lime-stones from which it can be obtained an object of great interest. From the results of the various geological surveys made in the United States, and in Europe, lime-stone, possessing hydraulic properties when calcined, may be looked for among those beds which are found in connection with the *shales*, or other argillaceous deposites. The celebrated *Roman*, or *Parker's cement*, of England, which, from its prompt induration in water, has become an important article of commerce, is manufactured from nodules of a concretionary argillaceous lime-stone, called *septaria*, from being traversed by veins of sparry carbonate of lime. Nodules of this character are found in Mass., and in some other States; and it is probable they would yield, if suitably calcined and ground, an article in nowise inferior to that imported.

30. *Gypsum*, or *Plaster of Paris*. This stone is a sulphate of lime, and has received its name from the extensive use made of it at Paris, and in its neighborhood, where it is quarried and sent to all parts of the world; being of a superior quality, owing, it is stated, to a certain portion of carbonate of lime which the stone contains. Gypsum is a very soft stone, and is not used as a building stone. Its chief utility is in furnishing a beautiful material for the ornamental casts and mouldings in the interior of edifices. For this purpose it is prepared by calcining, or, as the workmen term it, *boiling* the stone, until it is deprived of its water of crystallization. In this state it is made into a thin paste, and poured into moulds to form the cast, in which it hardens very promptly. Calcined plaster of Paris is also used as a cement for stone; but it is eminently unfit for this purpose; for when exposed, in any situation, to moisture it absorbs it with avidity, swells, cracks, and exfoliates rapidly.

Gypsum is found in various localities in the United States Large quantities of it are quarried in New York, both for building and agricultural purposes.

31. Durability of Stone. The most important properties of stone, as a building material, are its durability under the ordinary circumstances of exposure to weather; its capacity to sustain high degrees of temperature; and its resistance to the destructive action of fresh and salt water.

The wear of stone from ordinary exposure is very variable, depending, not only upon the texture and constituent elements of the stone, but also upon the locality and the position it may occupy in a structure, with respect to the prevailing driving rains. The chemist and geologist have not, thus far, laid down any infallible rules to guide the engineer in the selection of a material that may be pronounced durable for the ordinary period allotted to the works of man. In truth, the subject admits of only general indications; for stones having the same texture and chemical composition, from causes not fully ascertained, are found to possess very different degrees of duration. This has been particularly noted in feldspathic rocks. As a general rule, those stones which are fine-grained, absorb least water, and are of greatest specific gravity, are also most durable under ordinary exposures. The weight of a stone, however, may arise from a large proportion of iron in the state of a protoxide, a circumstance generally unfavorable to its durability. Besides, the various chemical combinations of iron, potash and clay, when found in considerable quantities, both in the primary and sedimentary silicious rocks, greatly affect their durability. The potash contained in feldspar dissolves, and carrying off a considerable proportion of the silica, leaves nothing but aluminous matter behind. The clay, on the other hand, absorbs water, becomes soft, and causes the stone to crumble to pieces. Iron in the form of protoxide, in some cases only, discolors the stone by its conversion into a peroxide. This discoloration, while it greatly diminishes the value of some stones, as in white marble, in others is not disagreeable to the eye, producing often a mottled appearance in buildings which adds to the picturesque effect.

32. Frost, or rather the alternate actions of freezing and thawing, is the most destructive agent of Nature with which the engineer has to contend. Its effects vary with the texture of stones; those of a fissile nature usually splitting, while the more porous kinds disintegrate, or exfoliate at the surface. When stone from a new quarry is to be tried, the best indication of its resistance to frost may be obtained from an examination of any rocks of the same kind, within its vicinity, which are known to have been exposed for a long period. Submitting the stone fresh from the quarry to the direct action of freezing would seem to be the most certain test, were the stone destroyed by the expansive action one of frost: but besides the uncertainty of this test, it is known

that some stones, which, when first quarried, are much affected by frost, splitting under its action, become impervious to it after they have lost the moisture of the quarry, as they do not re-absorb near so large an amount as they bring from the quarry.

33. M. Brard, a French chemist, has given a process for ascertaining the effects of frost on stone, which has met with the approval of many French architects and engineers of standing, as it corresponds with their experience. M. Brard directs that a small cubical block, about two inches on the edge, shall be carefully sawed from the stone to be tested. A cold saturated solution of sulphate of soda is prepared, placed over a fire, and brought to the boiling point. The stone, suspended from a string, is immersed in the boiling liquid, and kept there during thirty minutes; it is then carefully withdrawn; the liquid is decanted free from sediment into a flat vessel, and the stone is suspended over it in a cool cellar. An efflorescence of the salt soon makes its appearance on the stone, when it must be again dipped into the liquid. This should be done once or more frequently during the day and the process be continued in this way for about a week. The earthy sediment, found at the end of this period in the vessel, is weighed, and its quantity will give an indication of the like effect of frost. This process, with the official statement of a commission of engineers and architects, by whom it was tested, is minutely detailed in vol. 38, *Annales de Chimie et de Physique*, and the results are such as to commend it to the attention of engineers in submitting new stones to trial.

34. By the absorption of water, stones become softer and more friable. The materials for road coverings should be selected from those stones which absorb least water, and are also hard and not brittle. Granite, and its varieties, lime-stone, and common sand-stone, do not make good road materials of broken stone. All the hornblende rocks, porphyry, compact feldspar, and the quartzose rock associated with graywacke, furnish good, durable road coverings. The fine-grained granites which contain but a small proportion of mica, the fine-grained silicious sand-stones which are free from clay, and carbonate of lime, form a durable material when used in blocks for paving. Mica slate, talcose slate, hornblende slate, some varieties of gneiss, some varieties of sand-stone of a slaty structure, and graywacke slate, yield excellent materials for flag-stone.

35. The influence of locality on the durability of stone is very marked. Stone is observed to wear more rapidly in cities than in the country; and the stone in those parts of edifices exposed to the prevailing rains and winds, soonest exhibits signs of decay. The disintegration of the stratified stones placed in a wall, is mainly affected by the position which the strata or *quarry bed*

receives, with respect to the exposed surface; proceeding faster when the faces of the strata are exposed, than in the contrary position.

36. Stones which resist a high degree of heat without fusing are used for lining furnaces, and are termed fire-stones. A good fire-stone should not only be infusible, but also not liable to crack or exfoliate from heat. Stones that contain lime, or magnesia, except in the form of silicates, are usually unsuitable for fire-stones. Some porous silicious lime-stones, as well as some gypsous silicious rocks, resist moderate degrees of heat. Stones that contain much potash are very fusible under high temperatures, running into a glassy substance. Quartz and mica, in various combinations, furnish a good fire-stone; as, for example, finely granular quartz with thin layers of mica, mica slate of the same structure, and some kinds of gneiss which contain a large proportion of arenaceous quartz. Several varieties of sand-stone make a good lining for furnaces. They are usually those varieties which are free from feldspar, somewhat porous, and are uncrystallized in the mass. Talcose slate likewise furnishes a good fire-stone.

37. Hardness is an essential quality in stone exposed to wear from the attrition of hard bodies. Stones selected for paving, flagging, and steps for stairs, should be hard, and of a grain sufficiently coarse not to admit of becoming very smooth under the action to which they are submitted. As great hardness adds to the difficulty of working stone with the chisel, and to the cost of the prepared material, builders prefer the softer or *free-stones*, such as the lime-stones and sand-stones, for most building purposes. The following are some of the results, on this point, obtained from experiment.

Table showing the result of experiments made under the direction of Mr. Walker, on the wear of different stones in the tramway on the Commercial Road, London, from 27th March, 1830, *to 24th August,* 1831, *being a period of seventeen months. Transactions of Civil Engineers,* vol. 1.

Name of stone.	Sup. area in feet.	Original weight.			Loss of weight by wear.	Loss per sup. foot.	Relative losses.
		cwt.	qrs.	lbs.			
Guernsey . . .	4.734	7	1	12.75	4.50	0.951	1.000
Herme	5.250	7	3	24.25	5.50	1.048	1.102
Budle	6.336	9	0	15.75	7.75	1.223	1.286
Peterhead (blue) .	3.484	4	1	7.50	6.25	1.795	1.887
Heytor . . .	4.313	5	0	15.25	8.25	1.915	2.014
Aberdeen (red)	5.375	7	2	11.50	11.50	2.139	2.249
Dartmoor . . .	4.500	6	2	25.00	12.50	2.778	2.921
Aberdeen (blue) .	4.823	6	2	16.00	14.75	3.058	3.216

The Commercial Road stoneway consists of two parallel lines of rectangular tramstones, 18 inches wide by 12 inches deep, and jointed to each other endwise, for the wheels to travel on, with a common street pavement between for the horses.

The following table gives the results of some experiments on the wear of a fine-grained sand-stone pavement, by M. Coriolis, during 8 years, upon the paved road from Paris to Toulouse, the carriage over which is about 500 tons daily, published in the *Annales des Ponts et Chausées*, for March and April, 1834

Weight of a cubic foot.	Volume of water absorbed by the dry stone after one day's immersion, compared to that of the stone.	Mean annual wear.
158 lbs.	Neglected as insensible.	0.1023 inch.
154 "	"	0.1063 "
156 "	"	0.1299 "
150 "	$\frac{1}{13}$ in volume.	0.2126 "
148 "	$\frac{1}{17}$ "	0.2677 "

M. Coriolis remarks, that the weight of water absorbed affords one of the best indications of the durability of the fine-grained sand-stones used in France for pavements. An equally good test of the relative durability of stones of the same kind, M. Coriolis states, is the more or less clearness of sound given out by striking the stone with a hammer.

The following results are taken from an article by Mr. James Frost, *Civ. Engineer*, inserted in the *Journal of the Franklin Institute* for Oct. 1835, on the resistance of various substances to abrasion. The substances were abraded against a piece of white statuary marble, which was taken as a standard, represented by 100, by means of fine emery and sand. The relative resistance was calculated from the weight lost by each substance during the operation.

Comparative Resistance to Abrasion.

Aberdeen granite	980
Hard Yorkshire paving stone	327
Italian black marble	260
Kilkenny black marble	110
Statuary Marble	100
Old Portland stone	79
Roman cement stone	69
Fine-grained Newcastle grindstone	53
Stock brick	34
Coarse-grained Newcastle grindstone	14
Bath stone	12

LIME.

38. Lime, considered as a building material, is now usually divided into three principal classes; *Common*, or *Air lime*, *Hydraulic lime*, and *Hydraulic*, or *Water cement*.

39. Common, or air lime, is so called because the paste made from it with water will harden only in the air.

40. Hydraulic lime and hydraulic cement both take their name from hardening under water. The former differs from the latter in two essential points. It slakes thoroughly, like common lime, when deprived of its carbonic acid, and it does not harden promptly under water. Hydraulic cement, on the contrary, does not slake, and usually hardens very soon.

41. Our nomenclature, with regard to these substances, is still quite defective for scientific arrangement. For the lime-stones which yield hydraulic lime when completely calcined, also give an hydraulic cement when deprived of a portion only of their carbonic acid; and other lime-stones yield, on calcination, a result which can neither be termed lime nor hydraulic cement, owing to its slaking very imperfectly, and not retaining the hardness which it quickly takes when first placed under water.

M. Vicat, whose able researches into the properties of lime and mortars are so well known, has proposed to apply the term *cement lime-stones* (*calcaires à ciment*) to those stones which, when completely calcined, yield hydraulic cement, and which under no degree of calcination, will give hydraulic lime. For the lime-stones which yield hydraulic lime when completely calcined, and which, when subjected to a degree of heat insufficient to drive off all their carbonic acid, yield hydraulic cement, he proposes to retain the name hydraulic lime-stones; and to call the cement obtained from their incomplete calcination, *under-burnt* hydraulic cement, (*ciments d'incuits*,) to distinguish it from that obtained from the cement stone. With respect to those lime-stones which, by calcination, give a result that partakes partly of the properties both of limes and cements, he proposes for them the name of *dividing limes*, (*chaux limites*.)

The terms *fat* and *meager* are also applied to limes; owing to the difference in the quality of the paste obtained from them with the same quantity of water. The fat limes give a paste which is unctuous both to the sight and touch. The meager limes yield a thin paste. These names were of some importance when first introduced, as they served to distinguish common from hydraulic lime, the former being always fat, the latter meager; but, later experience having shown that all meager limes are not hydraulic, the terms are no longer of use, except to designate qualities of the paste of limes.

42. *Hydraulic Limes and Cements.* The lime-stones which yield these substances are either *argillaceous*, or *magnesian*, or *argilo-magnesian*. The products of their calcination vary considerably in their hydraulic properties Some of the hydraulic limes harden, or *set* very slowly under water, while others set rapidly. The hydraulic cements set in a very short time. This diversity in the hydraulic energy of the argillaceous lime-stones arises from the variable proportions in which the lime and clay enter into their composition.

43. M. Petot, a civil engineer in the French service, in an able work entitled *Recherches sur la Chauffournerie*, gives the following table, exhibiting these combinations, and the results obtained from their calcination.

Lime.	Clay.	Resulting products.	Distinctive characters of the products.
100	0	Very fat lime.	Incapable of hardening in water.
90	10	Lime a little hydraulic.	Slakes like pure lime, when properly calcined, and hardens under water.
80	20	do. quite hydraulic.	
70	30	do. do.	
60	40	Plastic, or hydraulic cement.	Does not slake under any circumstances, and hardens under water with rapidity.
50	50	do.	
40	60	do.	
30	70	Calcareous puzzolano (brick).	Does not slake nor harden under water, unless mixed with a fat, or an hydraulic lime.
20	80	do. do.	
10	90	do. do.	
0	100	Puzzolano of pure clay do.	Same as the preceding.

44. The most celebrated European hydraulic cements are obtained from argillaceous lime-stones, which vary but slightly in their constituent elements and properties. The following table gives the results of analyses to determine the relative proportions of lime and clay in these cements.

Table of Foreign Hydraulic Cements, showing the relative proportions of Clay and Lime contained in them.

LOCALITY.	Lime.	Clay.
English, (*commonly known as Parker's, or Roman cement*)	55.40	44.60
French, (*made from Boulogne pebbles*)	54.00	46.00
Do. (*Pouilly*)	42.86	57.14
Do. do.	36.37	63.63
Do. (*Baye*)	21 62	78.38
Russian	62.00	38.00

The hydraulic cements used in England are obtained from

various localities, and differ but little in the relative proportions of lime and clay found in them. Parker's cement, so called from the name of the person who first introduced it, is obtained by calcining nodules of *septaria*. The composition of these nodules is the same as that of the *Boulogne pebbles* found on the opposite coast of France. The stones which furnish the English and French hydraulic cements, contain but a very small amount of magnesia.

45. The best known hydraulic cements of the United States, are manufactured in the State of New York. The following analyses of some of the hydraulic lime-stones, from the most noted localities, published in the *Geological Report of the State of New York*, 1839, are given by Dr. Beck.

Analysis of the Manlius Hydraulic Lime-stone.

Carbonic acid	39.80
Lime	26.24
Magnesia	18.80
Silica and alumina	13.50
Oxide of iron	1.25
Moisture and loss	1.41
	100.00

This stone belongs to the same bed which yields the hydraulic cement obtained near Kingston, in Upper Canada.

Analysis of the Chittenango Hydraulic Lime-stone, before and after calcination.

	Unburnt.		Burnt.
Carbonic acid	39.33	Carbonic acid and moisture	10.90
Lime	25.00	Lime	39.50
Magnesia	17.83	Magnesia	22.27
Silica	11.76	Silica	16.56
Alumina	2.73	Alumina and oxide of iron	10.77
Peroxide of iron	1.50		
Moisture	1.50		100.00
	100.00		

Analysis of the Hydraulic Lime-stone from Ulster Co., along the line of the Delaware and Hudson Canal, before and after burning.

	Unburnt.	Burnt.
Carbonic acid	34.20	5
Lime	25.50	37.60
Magnesia	12.35	16.65
Silica	15.37	22.75
Alumina	9.13	13.40
Oxide of iron	2.25	3.30
Bituminous matter, moisture, and loss	1.20	1.30
	100.00	100.00

The hydraulic cement from this last locality has become generally well known, having been successfully used for most of the military and civil public works on the sea-board.

From the results of the analyses of all the above limestones, it appears that the proportions of lime and clay contained in them place them under the head of hydraulic cements, according to the classification of M. Petot. They do not slake, and they all set rapidly under water.

46. The discovery of the hydraulic properties of certain magnesian lime-stones is of recent date, and is due to M. Vicat, who first drew attention to the subject. M. Vicat inclines to the opinion, that magnesia alone, without the presence of some clay, will yield only a feeble hydraulic lime. He states, that he has never been able to obtain any other, from proceeding synthetically with common lime and magnesia; and that he knows of no well-authenticated instance in which any of the dolomites, either of the primitive or transition formations, have yielded a good hydraulic lime. The stones from these formations, he states, are devoid of clay; being very pure crystalline carbonates, or else contain silex only in the state of fine sand. From M. Vicat's experiments, it is rendered certain that carbonate of magnesia in combination with carbonate of lime, in the proportion of 40 parts of the latter to from 30 to 40 of the former, will produce a feebly hydraulic lime, which does not appear to increase in hardness after it has once set; but that with the same proportions, some hundredths of clay are requisite to give hydraulic energy to the compound. This proportion of clay M. Vicat supposes may cause the formation of triple *hydro-silicates* of lime, alumina, and magnesia, having all the characteristic properties of good hydraulic lime.

47. The hydraulic properties of the magnesian lime-stones of

the United States were noticed by Professor W. B. Rogers, who, in his *Report of the Geological Survey of Virginia*, 1838, has given the following analyses of some of the stones from different localities.

	No. 1.	No. 2.	No. 3.	No. 4.
Carbonate of lime	55.80	53.23	48.20	55.03
Carbonate of magnesia	39.20	41.00	35.76	24.16
Alumina and oxide of iron	1.50	0.80	1.20	2.60
Silica and insoluble matter	2.50	2.80	12.10	15.30
Water	0.40	0.40	2.73	1.20
Loss	0.60	1.77	0.01	1.71
	100.00	100.00	100.00	100.00

The lime-stone No. 1 of the above table is from Sheppardstown on the Potomac, in Virginia; it is extensively manufactured for hydraulic cement. No. 2 is from the Natural Bridge, and banks of Cedar Creek, Virginia; it makes a good hydraulic cement. No. 3 is from New York, and is extensively burnt for cement. No. 4 is from Louisville, Kentucky; said to make a good cement.

48. M. Vicat states, that a magnesian lime-stone of France containing the following constituents, lime 40 parts, magnesia 21, and silica 21, yields a good hydraulic cement; and he gives the following analysis of a stone which gives a good hydraulic lime.

Carbonate of lime	50.60
Carbonate of magnesia	42.00
Silica	5.00
Alumina	2.00
Oxide of iron	0.40
	100.00

By comparing the constituents of these two last stones with the analyses of the cement-stones of New York, and the magnesian hydraulic lime-stones of Prof. Rogers, it will be seen that they consist, respectively, of nearly the same combinations of lime, magnesia, and silica.

49. *Physical Characters and Tests of Hydraulic Lime-stones.* The simple external characters of a lime-stone, as color, texture, fracture, and taste, are insufficient to enable a person to decide whether it belongs to the hydraulic class; although they assist conjecture, particularly if the rock, from which the specimen is taken, is found in connection with the clay deposites, or if it belong to a stratum whose general level and characteristics are the

same as the argilo-magnesian rocks. These rocks are generally some shade of drab, or of gray, or of a dark grayish blue; have a compact texture; fracture even or conchoidal; with a clayey or earthy smell and taste. Although the hydraulic lime-stones are usually colored, still it may happen that the stone may be of a pure white, arising from the combination of lime with a pure clay.

The difficulty of pronouncing upon the class to which a lime-stone belongs, from its physical properties alone, renders it necessary to resort to a chemical analysis, and even to direct experiment, to decide the question.

50. In making a complete chemical analysis of a lime-stone, more skill in chemical manipulations is requisite than engineers usually possess; but a person who has the ordinary elementary knowledge of chemistry, can readily ascertain the quantity of clay or of magnesia contained in a lime-stone, and from these two elements can pronounce, with tolerable certainty, upon its hydraulic properties. To arrive at this conclusion, a small portion of the stone to be tested—about five drachms—is taken and reduced to a powder; this is placed in a capsule, or an ordinary watch crystal, and slightly diluted muriatic acid is poured over it until it ceases to effervesce. The capsule is then gently heated, and the liquor evaporated, until the residue in the capsule has acquired the consistence of thin paste. This paste is thrown into a pint of pure water and well shaken up, and the mixture is then filtered. The residue left on the filtering paper is thoroughly dried, by bringing it to a red heat; this being weighed will give the clay, or insoluble matter, contained in the stone. It is important to ascertain the state of mechanical division of the insoluble matter thus obtained; for if it be wholly granular, the stone will not yield hydraulic lime. The granular portion must therefore be carefully separated from the other before the latter is dried and weighed.

51. If the sample tested contains magnesia, an indication of this will be given by the slowness with which the acid acts; if the quantity of magnesia be but little, the solution will at first proceed rapidly and then become more sluggish. To ascertain the quantity of magnesia, clear lime-water must be added to the filtered solution as long as any precipitate is formed, and this precipitate must be quickly gathered on filtering paper, and then be washed with pure water. The residue from this washing is the magnesia. It must be thoroughly dried before being weighed, to ascertain its proportion to the clay.

52. Having ascertained, by the preceding analysis, the probable hydraulic energy of the stone, a sample of it should also be submitted to direct experiment. This may be likewise done on a small scale. A sample of the stone must be reduced to frag

ments about the size of a walnut. A crucible, perforated with holes for the free admission of air, is filled with these fragments, and placed over a fire sufficiently powerful to drive off the car bonic acid of the stone. The time for effecting this will depend on the intensity of the heat. When the heat has been applied for three or four hours, a small portion of the calcined stone may be tried with an acid, and the degree of the calcination may be judged of by the more or less copiousness of the effervescence that ensues. If no effervescence takes place, the operation may be considered completed. The calcined stone should be tried soon after it has become cold; otherwise, it should be kept in a glass jar made as air-tight as practicable until used.

53. When the calcined stone is to be tried, it is first slaked by placing it in a small basket, which is immersed for five or six seconds in pure water. The stone is emptied from the basket so soon as the water has drained off, and is allowed to stand until the slaking is terminated. This process will proceed more or less rapidly, according to the quality of the stone, and the degree of its calcination. In some cases, it will be completed in a few minutes; in others, portions only of the stone will fall to powder, the rest crumbling into lumps which slake very sluggishly; while other varieties, as the true cement stones, give no evidence of slaking. If the stone slakes either completely or partially, it must be converted into a paste of the consistence of soft putty, being ground up thoroughly, if necessary, in an iron mortar. The paste is made into a cake, and placed on the bottom of an ordinary tumbler, care being taken to make the diameter of the cake the same as that of the tumbler, which is filled with water, and the time of immersion noted. If the lime is only moderately hydraulic, it will have become hard enough at the end of fifteen or twenty days, to resist the pressure of the finger, and will continue to harden slowly, more particularly from the sixth or eighth month after immersion; and at the end of a year it will have acquired the consistency of hard soap, and will dissolve slowly in pure water. A fair hydraulic lime will have hardened so as to resist the pressure of the finger, in about six or eight days after immersion, and will continue to grow harder until from six to twelve months after immersion; it will then have acquired the hardness of the softest calcareous stones, and will be no longer soluble in pure water. When the stone is eminently hydraulic, it will have become hard in from two to four days after immersion, and in one month it will be quite hard and insoluble in pure water; after six months, its hardness will be about equal to the more absorbent calcareous stones; will splinter from a blow, presenting a slaty fracture.

As the hydraulic cements do not slake perceptibly, the burnt

stone must first be reduced to a fine powder before it is made into a paste. The paste, when kneaded between the fingers, becomes warm, and will generally set in a few minutes, either in the open air or in water. Hydraulic cement is far more sparingly soluble in pure water than the hydraulic lime; and the action of pure water upon them ceases, apparently, after a few weeks immersion in it.

54. *Calcination of Lime-stone*. The effect of heat on lime-stones varies with the constituent elements of the stone. The pure lime-stones will stand a high degree of temperature without fusing, losing only their carbonic acid and water. The impure stones containing silica fuse completely under a great heat, and become more or less vitrified when the temperature much exceeds a red heat. The action of heat on the impure lime-stones, besides driving off their carbonic acid and water, modifies the relations of their other chemical constituents. The argillaceous stones, for example, yield an insoluble precipitate when acted on by an acid before calcination, but are perfectly soluble afterwards, unless the silex they contain happens to be in the form of grains.

55. The calcination of the hydraulic lime-stones, from their fusible nature, requires to be conducted with great care; for, if not pushed far enough, the under-burnt portions will not slake; and, if carried too far, the stone becomes *dead* or sluggish; slakes very slowly and imperfectly at first; and, if used in this state for masonry, may do injury by the swelling which accompanies the after-slaking.

56. The more or less facility with which the impure lime-stones can be burned, depends upon several causes; as the compactness of the stone; the size of the fragments submitted to heat; and the presence of a current of air, or of aqueous vapor. The more compact stones yield their carbonic acid less readily than those of an opposite texture. Stones which, when broken into very small lumps, can be calcined under the red heat of an ordinary fire in a few hours, will require a far greater degree of temperature, and for a much longer period, when broken into fragments of six or eight inches in diameter. This is particularly the case with the impure lime-stones, which, when in large lumps, vitrify at the surface before the interior is thoroughly burnt.

57. If a current of vapor is passed over the stone after it has commenced to give off its carbonic acid, the remaining portion of the gas which, under ordinary circumstances, is expelled with great difficulty, particularly near the end of the process of calcination, will be carried off much sooner. This influence of an aqueous current is attributed, by M. Gay-Lussac, purely to a mechanical action, by removing the gas as it is evolved, and his experiments go to show that a like effect is produced by an at

mospheric current. In burning the impure lime-stones, howevei an aqueous current produces the further beneficial effect of pre venting the vitrification of the stone, when the temperature has become too elevated; but as the vapor, on coming in contact with the heated stone, carries off a large portion of the heat, this, together with the latent heat contained in it, may render its use in some cases, far from economical.

58. Wood, charcoal, peat, the bituminous and anthracite coals are used for fuel in lime-burning. M. Vicat states, that wood is the best fuel for burning hydraulic lime-stones; that charcoal is inferior to bituminous coal; and that the results from this last are very uncertain. When wood is used, it should be dry and split up, to burn quickly and give a clear blaze. The common opinion among lime-burners, that the greener the fuel the better, and that the lime-stone should be watered before it is placed in the kiln, is wrong; as a large portion of the heat is consumed in converting the water in both cases into vapor. Coal is a more economical fuel than wood, and is therefore generally preferred to it; but it requires particular care in ascertaining the proper quantity for use.

59. *Lime-kilns*. Great diversity is met with in the forms and proportions of lime-kilns. Wherever attention has been paid to economy in fuel, the *cylindrical*, *ovoidal*, or the *inverted conical* form has been adopted. The two first being preferred for wood and the last for coal.

60. The whole of the burnt lime is either drawn from the kiln at once, or else the burning is so regulated, that fresh stone and fuel are added as the calcined portions are withdrawn. The latter method is usually followed when the fuel used is coal. The stone and coal, broken into proper sizes, (Fig. 1,) and in propor-

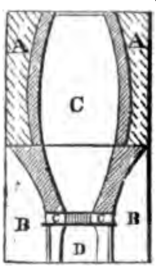


Fig. 1 represents a vertical section through the axis and centre lines of the entrances communicating with the interior of a kiln for burning lime with coal.
A, solid masonry of the kiln, which is built up on the exterior like a square tower, with two arched entrances at B, B on opposite sides.
C, interior of the kiln, lined with fire-brick or stone.
D, ash-pit.
c, c, openings between B, B and the interior through which the burnt lime is drawn.

tions determined by experiment, are placed in the kiln in alternate layers; the coal is ignited at the bottom of the kiln, and fresh strata are added at the top, as the burnt mass settles down and is partially withdrawn at the bottom. Kilns used in this way are called *perpetual kilns;* they are more economical in the con sumption of fuel than those in which the burning is intermitted and which are, on this account, termed *intermittent kilns*. Wor

may also be used as fuel in perpetual kilns, but not with such economy as coal; it moreover presents many inconveniences, in supplying the kiln with fresh stone, and in regulating its discharge. The inverted conical-shaped kiln is generally adopted for coal, and the ovoidal-shaped for wood.

61. Some care is requisite in filling the kiln with stone when a wood fire is used. A dome (Fig. 2) is formed of the largest blocks

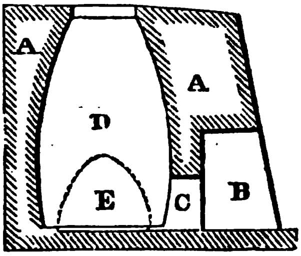


Fig. 2 represents a vertical section through the axis and centre line of the entrance of a lime-kiln for wood.
A, solid masonry of the kiln.
B, arched entrance.
C, doorway for drawing kiln and supplying fuel.
D, interior of kiln.
E, dome of broken stone, shown by the dotted line.

of the broken stone, which either rests on the bottom of the kiln or on the ash-grate. The lower diameter of the dome is a few feet less than that of the kiln; and its interior is made sufficiently capacious to receive the fuel which, cut into short lengths, is placed up endwise around the dome. The stone is placed over and around the courses which form the dome, the largest blocks in the centre of the kiln. The management of the fire is a matter of experiment. For the first eight or ten hours it should be carefully regulated, in order to bring the stone gradually to a red heat. By applying a high heat at first, or by any sudden increase of it until the mass has reached a nearly uniform temperature, the stone is apt to shiver, and choke the kiln, by stopping the voids between the courses of stone which form the dome. After the stone is brought to a red heat, the supply of fuel should be uniform until the end of the calcination. The practice sometimes adopted, of abating the fire towards the end, is bad, as the last portions of carbonic acid retained by the stone, require a high degree of heat for their expulsion. The indications of complete calcination are generally manifested by the diminution which gradually takes place in the mass, and which, at this stage, is about one sixth of the primitive volume; by the broken appearance of the stone which forms the dome, the interstices between which being also choked up by fragments of the burnt stone; and by the ease with which an iron bar may be forced down through the burnt stone in the kiln. When these indications of complete calcination are observed, the kiln should be closed for ten or twelve hours, to confine the heat and finish the burning of the upper strata.

62. The form and relative dimensions of a kiln for wood can

be determined only by careful experiment. If too great height be given to the mass, the lower portions may be overburned before the upper are burned enough. The proportions between the height and mean horizontal section, will depend on the texture of the stone; the size of the fragments into which it is broken for burning; and the more or less facility with which it vitrifies. In the memoir of M. Petot, already cited, it is stated as the results of experiments made at Brest, that large-sized kilns are more economical, both in the consumption of fuel and in the cost of attendance, than small ones; but that there is no notable economy in fuel when the mean horizontal section of the kiln exceeds sixty square feet.

63. The circular seems the most suitable form for the horizontal sections of a kiln, both for strength and for economizing the heat. Were the section the same throughout, or the form of the interior of the kiln cylindrical, the strata of stone, above a certain point, would be very imperfectly burned when the lower were enough so, owing to the rapidity with which the inflamed gases, arising from the combustion, are cooled by coming into contact with the stone. To procure, therefore, a temperature throughout the heated mass which shall be nearly uniform, the horizontal sections of the kiln should gradually decrease from the point where the flame rises, which is near the top of the dome of broken stone, to the top of the kiln. This contraction of the horizontal section, from the bottom upward, should not be made too rapidly, as the draft would be injured, and the capacity of the kiln too much diminished; and in no case should the area of the top opening be less than about one fourth the area of the section taken near the top of the dome. The best manner of arranging the sides of the kiln, in the plane of the longitudinal section, is to connect the top opening with the horizontal section through the top of the dome, by an arc of a circle whose tangent at the lower point shall be vertical.

64. Lime-kilns are constructed either of brick, or of some of the more refractory stones. The walls of the kiln should be sufficiently thick to confine the heat, and, when the locality admits of it, they are built into a side hill; otherwise, it may be necessary to use iron hoops, and vertical bars of iron, to strengthen the brick-work. The interior of the kiln should be faced either with good fire-brick or with fire-stone.

65. M. Petot prefers kilns arranged with fire-grates, and an ash-pit under the dome of broken stone, for the reason that they give the means of better regulating the heat, and of throwing the flame more in the axis of the kiln than can be done in kilns without them. The action of the flame is thus more uniformly felt through the mass of stone above the top of the dome, while that

of the radiated heat upon the stone around the dome, is also more uniform.

66. M. Petot states, that the height of the mass of stone above the top of the dome should not be greater than from ten to thirteen feet, depending on the more or less compact texture of the stone, and the more or less ease with which it vitrifies. He proposes to use kilns with two stories, (Fig. 3,) for the purpose

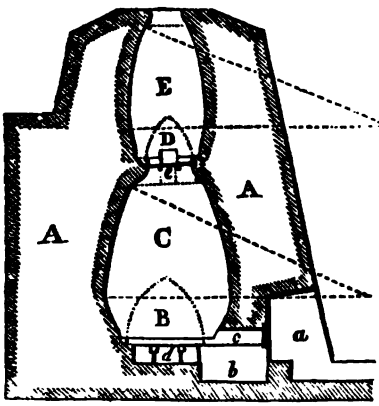


Fig. 3 represents a vertical section through the axis and centre line of the entrance of a lime-kiln with two stories for wood.
A, solid masonry of the kiln.
B, dome shown by the dotted line.
C, interior of lower story.
D, dome of upper story.
E, interior of upper story.
a, arched entrance to kiln.
b, receptacle for water to furnish a current of aqueous vapor.
c, doorway for drawing kiln, &c., closed by a fire-proof door.
d, ash-pit under fire-grate.
e, upper doorway for drawing kiln, &c

of economizing the fuel, by using the heat which passes off from the top of the lower story, and would otherwise be lost, to heat the stone in the upper story; this story being arranged with a side-door, to introduce fuel under its dome of broken stone, and complete the calcination when that of the stone in the lower story is finished.

M. Petot gives the following general directions for regulating the relative dimensions of the parts of the kiln. The greatest horizontal section of the kiln is placed rather below the top of the dome of broken stone; the diameter of this section being 1.82, the diameter of the grate. The height of the dome above the grate is from 3 to 6 feet, according to the quantity of fuel to be consumed hourly. The bottom of the kiln, on which the piers of the dome rest, is from 4 to 6 inches above the top of the grate; the diameter of the kiln at this point being about 2 feet 9 inches greater than that of the grate. The diameter of the horizontal section at top is 0.63, the diameter of the greatest horizontal section. The horizontal sections of the kiln diminish from the section near the top of the dome to the top and bottom of the kiln; the sides of the kiln receiving the form shown in Fig. 3: the object of contracting the kiln towards the bottom being to allow the stone near the bottom of the kiln to be thoroughly burned by the radiated heat The grate is formed of cast-iron bars of the usual form

the area of the spaces between the bars being one fourth the total area of the grate. The bottom of the ash-pit, which may be on the same level as the exterior ground, is placed 18 inches below the grate; and at the entrance to the ash-pit is placed a reservoir for water, about 18 inches in depth, to furnish an aqueous current. The draft through the grate is regulated by a lateral air channel to the ash-pit, which can be totally or partially shut by a valve; the area of the cross section of this channel is one tenth the total area of the grate. A square opening 16 inches wide, the bottom of which is on a level with the bottom of the kiln, leads to the dome for the supply of the fuel. This opening is closed with a fire-proof and air-tight door.

In arranging a kiln with two stories, M. Petot states, that the grates of the upper story are so soon destroyed by the heat, that it is better to suppress them, and to place the fuel for completing the calcination of the stone of this story, on the top of the burnt stone of the lower story.

67. *Slaking Lime.* Quick-lime may be slaked in three different ways. By pouring sufficient water on the burnt stone to convert the slaked lime into a thin paste, which is termed *drowning* the lime. By placing the burnt stone in a basket, and immersing it for a few seconds in water, during which time it will imbibe enough water to cause it to fall, by slaking, into a dry powder; or by sprinkling the burnt stone with a sufficient quantity of water to produce the same effect. By allowing the stone to slake spontaneously, from the moisture it imbibes from the atmosphere, which is termed *air-slaking*.

68. Opinion seems to be settled among engineers, that drowning is the worst method of slaking lime which is to be used for mortars. When properly done, however, it produces a finer paste than either of the other methods; and it may therefore be resorted to whenever a paste of this character, or a whitewash is wanted. Some care, however, is requisite to produce this result. The stone should be fresh from the kiln, otherwise it is apt to slake into lumps or fine grit. All the water used should be poured over the stone at once, which should be arranged in a basin or vessel, so that the water surrounding it may be gradually imbibed as the slaking proceeds. If fresh water be added during the slaking, it checks the process, and causes a gritty paste to form.

69. In slaking by immersion, or by sprinkling with water, the stone should be reduced to small-sized fragments, otherwise the slaking will not proceed uniformly. The fat limes should be in lumps, about the size of a walnut, for immersion; and, when withdrawn from the water, should be placed immediately in bins or be covered with sand, to confine the heat and vapor. If left exposed to the air, the lime becomes chilled and separates into a

coarse grit, which takes some time to slake thoroughly when more water is added. Sprinkling the lime is a more convenient process than immersion, and is equally good. To effect the slaking in this way, the stone should be broken into fragments of a suitable size, which experiment will determine, and be placed in small heaps, surrounded by sufficient sand to cover them up when the slaking is nearly completed. The stone is then sprinkled with about one fourth its bulk of water, poured through the rose of a watering-pot, those lumps which seem to slake most sluggishly receiving the most water; when the process seems completed, the heap is carefully covered over with the sand, and allowed to remain a day or two before it is used.

70. Slaking either by immersion or by sprinkling is considered the best. The quantity of water imbibed by lime when slaked by immersion, varies with the nature of the lime; 100 parts of fat lime will take up only 18 parts of water; and the same quantity of meager lime will imbibe from 20 to 35 parts. One volume, in powder, of the burnt stone of rich lime yields from 1.50 to 1.70 in volume of powder of slaked lime; while one volume of meager lime, under like circumstances, will yield from 1.80 to 2.18 in volume of slaked lime.

71. Quick lime, when exposed to the free action of the air in a dry locality, slakes slowly, by imbibing moisture from the atmosphere, with a slight disengagement of heat. Opinion seems to be divided with regard to the effect of this method of slaking on fat limes. Some assert, that the mortar made from them is better than that obtained from any other process, and attribute this result to the re-conversion of a portion of the slaked lime into a carbonate; others state the reverse to obtain, and assign the same cause for it. With regard to hydraulic limes, all agree that they are greatly injured by air-slaking.

72. Air-slaked fat limes increase two fifths in weight, and for one volume of quick lime yield 3.52 volumes of slaked lime. The meager limes increase one eighth in weight, and for one volume of quick lime yield from 1.75 to 2.25 volumes of slaked lime

73. The dry hydrates of lime, when exposed to the atmosphere, gradually absorb carbonic acid and water. This process proceeds very slowly, and the slaked lime never regains all the carbonic acid which is driven off by the calcination of the lime-stone. When converted into a thick paste, and exposed to the air, the hydrates gradually absorb carbonic acid; this action first takes place on the surface, and proceeds more slowly from year to year towards the interior of the exposed mass. The absorption of gas proceeds more rapidly in the meager than in the fat limes. Those hydrates which are most thoroughly slaked become hardest. The hydrates of the pure fat limes become in time very

hard, while those of the hydraulic limes become only moderately hard.

74. The fat limes, when slaked by drowning, may be preserved for a long period in the state of paste, if placed in a damp situation and kept from contact with the air. They may also be preserved for a long time without change, when slaked by immersion to a dry powder, if placed in covered vessels. Hydraulic limes, under similar circumstances, will harden if kept in the state of paste, and will deteriorate when in powder, unless kept in perfectly air-tight vessels.

75. The hydrates of fat lime, from air-slaking or immersion, require a smaller quantity of water to reduce them to the state of paste than the others; but, when immersed in water, they gradually imbibe their full dose of water, the paste becoming thicker, but remaining unchanged in volume. Exposed in this way, the water will in time dissolve out all the lime of the hydrate which has not been re-converted into a sub-carbonate, by the absorption of carbonic acid before immersion; and if the water contain carbonic acid, it will also dissolve the carbonated portions.

76. The hydrates of hydraulic lime, when immersed in water in the state of thin pastes, reject a portion of the water from the paste, and become hard in time; if the paste be very stiff, they imbibe more water, set quickly, and acquire greater hardness in time than the soft pastes. The pastes of the hydrates of hydraulic lime, which have hardened in the air, will retain their hardness when placed in water.

77. The pastes of the fat limes shrink very unequally in drying, and the shrinkage increases with the purity of the lime; on this account it is difficult to apply them alone to any building purposes, except in very thin layers. The pastes of the hydraulic limes can only be used with advantage under water, or where they are constantly exposed to humidity; and in these situations they are never used alone, as they are found to succeed as well, and to present more economy, when mixed with a portion of sand

78. *Manner of Reducing Hydraulic Cement.* As the cement stones will not slake, they must be reduced to a fine powder by some mechanical process, before they can be converted into a hydrate. The methods usually employed for this purpose consist in first breaking the burnt stone into small fragments, either under iron cylinders, or in mills suitably formed for this purpose, which are next ground between a pair of stones, or else crushed by an iron roller. The coarser particles are separated from the fine powder by the ordinary processes with sieves. The powder is then carefully packed in air-tight casks, and kept for use

79. Hydraulic cement, like hydraulic lime, deteriorates by exposure to the air, and may in time lose all its hydraulic prop-

erties. On this account it should be used when fresh from the kiln; for, however carefully packed, it cannot be well preserved when transported to any distance.

80. The deterioration of hydraulic cements, from exposure to the air, arises, probably, from a chemical disunion between the constituent elements of the burnt stone, occasioned by the absorption of water and carbonic acid. When injured, their energy can be restored by submitting them to a much slighter degree of heat than that which is requisite to calcine the stone suitably in the first instance. From the experiments of M. Petot, it appears that a red heat, kept up for a short period, is sufficient to restore damaged hydraulic cements.

81. *Artificial Hydraulic Limes and Cements.* The discovery of the argillaceous character of the stones which yield hydraulic limes and cements, connected with the fact that brick reduced to a fine powder, as well as several substances of volcanic origin having nearly the same constituent elements as ordinary brick when mixed in suitable proportions with common lime, will yield a paste that hardens under water, has led, within a recent period, to artificial methods of producing compounds possessing the properties of natural hydraulic lime-stones.

82. M. Vicat was the first to point out the method of forming an artificial hydraulic lime, by mixing common lime and unburnt clay, in suitable proportions, and then calcining them. The experiments of M. Vicat have been repeated by several eminent engineers with complete success, and among others by General Pasley, who, in a recent work by him, *Observations on Limes, Calcareous Cements,* &c., has given, with minute detail, the results of his experiments; from which it appears that an hydraulic cement, fully equal in quality to that obtained from natural stones can be made by mixing common lime, either in the state of a carbonate or of a hydrate, with clay, and subjecting the mixture to a suitable degree of heat. In some parts of France, where chalk is found abundantly, the preparation of artificial hydraulic lime has become a branch of manufacture.

83. Different methods have been pursued in preparing this material, the main object being to secure the finest mechanical division of the two ingredients, and their thorough mixture. For this purpose the lime-stone, if soft like chalk or tufa, may be reduced in a wash-mill, or a rolling-mill, to the state of a soft pulp; it is then incorporated with the clay, by passing them through a pug-mill. The mixture is next moulded into small blocks, or made up into balls between 2 and 3 inches diameter, by hand, and well dried. The balls are placed in a kiln,—suitably calcined, and are finally slaked, or ground down fine for use.

84. If the lime-stone be hard, it must be calcined and slaked

in the usual manner, before it can be mixed with the clay. The process for mixing the ingredients, their calcination, and farther preparation for use, are the same as in the preceding case.

85. Artificial hydraulic lime, prepared from the hard lime-stones, is more expensive than that made from the soft; but it is stated to be superior in quality to the latter.

86. As clays are seldom free from carbonate of lime, and as the lime-stones which yield common or fat lime may contain some portion of clay, the proper proportions of the two ingredients, to produce either an hydraulic lime or a cement, must be determined by experiment in each case, guided by a previous analysis of the two ingredients to be tried.

If the lime be pure, and the clay be free from lime, then the combinations in the proportions given in the table of M. Petot will give, by calcination, like results with the same proportions when found naturally combined.

87. *Puzzolana*, &c. The practice of using brick or tile-dust, or a volcanic substance known by the name of puzzolana, mixed with common lime, to form an hydraulic lime, was known to the Romans, by whom mortars composed of these materials were extensively used in their hydraulic constructions. This practice has been more or less followed by modern engineers, who, until within a few years, either used the puzzolana of Italy, where it is obtained near Mount Vesuvius, in a pulverulent state, or a material termed *Trass*, manufactured in Holland, by grinding to a fine powder a volcanic stone obtained near Andernach on the Rhine.

Experiments by several eminent chemists have extended the list of natural substances which, when properly burnt and reduced to powder, have the same properties as puzzolana. They mostly belong to the feldspathic and schistose rocks, and are either fine sand, or clays more or less indurated.

The following Table gives the results of analyses of Puzzolana, Trass, a Basalt, and a Schistus, which, when burnt and powdered, were found to possess the properties of puzzolana.

	Puzzolana.	Trass.	Basalt.	Schistus.
Silica	0.445	0.570	44.50	46.00
Alumina	0.150	0.120	16.75	26.00
Lime	0.088	0.026	9.50	4.00
Magnesia	0.047	0.010	–	–
Oxide of iron	0.120	0.050	20.00	14.00
Oxide of manganese	–	–	2.37	8.00
Potassa	0.014	0.070	–	–
Soda	0.030	0.010	2.60	–
Water and loss	0.106	0.144	4.28	2.00
	1.000	1.000	100.00	100.00

88. All of these substances, when prepared artificially, are now generally known by the name of *artificial puzzolanas*, in contradistinction to those which occur naturally.

89. General Treussart, of the French Corps of Military Engineers, first attempted a systematic investigation of the properties of artificial puzzolanas made from ordinary clay, and of the best manner of preparing them on a large scale. It appears from the results of his experiments, that the plastic clays used for tiles, or pottery, which are unctuous to the touch, the alumina in them being in the proportion of one fifth to one third of the silica, furnish the best artificial puzzolanas when suitably burned. The clays which are more meager, and harsher to the touch, yield an inferior article, but are in some cases preferable, from the greater ease with which they can be reduced to a powder.

90. As the clays mostly contain lime, magnesia, some of the metallic oxides, and alkaline salts, General Treussart endeavored to ascertain the influence of these substances upon the qualities of the artificial puzzolanas from clays in which they are found. He states, that the carbonate of potash and the muriate of soda seem to act beneficially; that magnesia seems to be passive, as well as the oxide of iron, except when the latter is found in a large proportion, when it acts hurtfully; and that the lime has a material influence on the degree of heat required to convert the clay into a good artificial puzzolana.

91. The management of the heat, in the preparation of this material, seems of the first consequence; and General Treussart recommends that direct experiment be resorted to, as the most certain means of ascertaining the proper point. For this purpose, specimens of the clay to be tried may be kneaded into balls as large as an egg, and the balls, when dry, be submitted to different degrees of heat in a kiln, or furnace, through which a current of air must pass over the balls, as this last circumstance is essential to secure a material possessing the best hydraulic qualities. Some of the balls are withdrawn as soon as their color indicates that they are underburnt; others when they have the appearance of well-burnt brick; and others when their color shows that they are overburnt, but before they become vitrified. The burnt balls are reduced to an impalpable powder, and this is mixed with a hydrate of fat lime, in the proportion of two parts of the powder to one of lime in paste. Water is added, if necessary, to bring the different mixtures to the consistence of a thick pulp; and they are separately placed in glass vessels, covered with water, and allowed to remain until they harden. The compound which hardens most promptly will indicate the most suitable degree of heat to be applied.

92. As the carbonates of lime, of potash, and of soda, act as

fluxes on silica, the presence of either one of them will modify the degree of heat necessary to convert the clay into a good natural puzzolana. Clay, containing about one tenth of lime, should be brought to about the state of slightly-burnt brick. The ochreous clays require a higher degree of heat to convert them into a good material, and should be burnt until they assume the appearance of well-burnt brick. The more refractory clays will bear a still higher degree of heat; but the calcination should in no case be carried to the point of incipient vitrification.

93. The quantity of lime contained in the clay can be readily ascertained beforehand, by treating a small portion of the clay, diffused in water, with enough muriatic acid to dissolve out the lime; and this last might serve as a guide in the preliminary stages of the experiments.

94. General Treussart states, as the results of his experiments, that the mixture of artificial puzzolana and fat lime forms an hydraulic paste superior in quality to that obtained by M. Vicat's process for making artificial hydraulic lime. M. Curtois, a French civil engineer, in a memoir on these artificial compounds, published in the *Annales des Ponts et Chaussées*, 1834, and General Pasley, more recently, adopt the conclusion of General Treussart. M. Vicat's process appears best adapted when chalk, or any very soft lime-stone, which can be readily converted to a soft pulp, is used, as offering more economy, and affording an hydraulic lime which is sufficiently strong for most building purposes. By it General Pasley has succeeded in obtaining an artificial hydraulic cement, which is but little, if at all, inferior to the best natural varieties; a result which has not been obtained from any combination of fat lime with puzzolana, whether natural, or artificial.

95. All the puzzolanas possess the important property of not deteriorating by exposure to the air, which is not the case with any of the hydraulic limes, or cements. This property may render them very serviceable in many localities, where only common, or feebly hydraulic lime can be obtained.

MORTAR.

96. *Mortar* is any mixture of lime in paste with sand. It may be divided into two principal classes; *Hydraulic mortar*, which is made of hydraulic lime, and *Common mortar*, made of common lime.

97. The term *Grout* is applied to any mortar in a thin or fluid state; and the terms *Concrete* and *Beton*, to mortars incorporated with gravel and small fragments of stone or brick.

98. Mortar is used for various purposes in building. It serves as a cement to unite blocks of stone, or brick. In concrete and

beton, which may be regarded as *artificial conglomerate stones*. It forms the *matrix* by which the gravel and broken stone are held together; and it is the principal material with which the exterior surfaces of walls and the interior of edifices are coated.

99. The quality of mortars, whether used for structures exposed to the weather, or for those immersed in water, will depend upon the nature of the materials used;—their proportion;—the manner in which the lime has been converted into a paste to receive the sand;—and the mode employed to mix the ingredients. Upon all of these points experiment is the only unerring guide for the engineer; for the great diversity in the constituent elements of lime-stones, as well as in the other ingredients of mortars, must necessarily alone give rise to diversities in results; and when, to these causes of variation, are superadded those resulting from different processes pursued in the manipulations of slaking the lime and mixing the ingredients, no surprise should be felt at the seemingly opposite conclusions at which writers, who have pursued the subject experimentally, have arrived. From the great mass of facts, however, presented on this subject within a few years, some general rules may be laid down, which the engineer may safely follow, in the absence of the means of making direct experiments.

100. *Sand.* This material, which forms one of the ingredients of mortar, is the granular product arising from the disintegration of rocks. It may, therefore, like the rocks from which it is derived, be divided into three principal varieties—the silicious, the calcareous, and the argillaceous.

Sand is also named from the locality where it is obtained, as *pit-sand*, which is procured from excavations in alluvial, or other deposites of disintegrated rock; *river-sand* and *sea-sand*, which are taken from the shores of the sea, or rivers.

Builders again classify sand according to the size of the grain. The term *coarse sand* is applied when the grain varies between $\frac{1}{8}$th and $\frac{1}{16}$th of an inch in diameter; the term *fine sand*, when the grain is between $\frac{1}{16}$th and $\frac{1}{32}$th of an inch in diameter; and the term *mixed sand* is used for any mixture of the two preceding kinds.

101. The silicious sands, arising from the quartzose rocks, are the most abundant, and are usually preferred by builders. The calcareous sands, from hard calcareous rocks, are more rare, but form a good ingredient for mortar. Some of the argillaceous sands possess the properties of the less energetic puzzolanas, and are therefore very valuable, as forming, with common lime, an artificial hydraulic lime.

102. The property which some argillaceous sands possess, of forming with common, or slightly hydraulic lime a compound which

will harden under water, has been long known in France, where these sands are termed *arènes*. The sands of this nature are usually found in hillocks along river valleys. These hillocks sometimes rest on calcareous rocks, or argillaceous tufas, and are frequently formed of alternate beds of the sand and pebbles. The sand is of various colors, such as yellow, red, and green, and seems to have been formed from the disintegration of clay in a more or less indurated state. The arènes are not as energetic as either natural or artificial puzzolanas; still they form, with common lime, an excellent mortar for masonry exposed either to the open air, or to humid localities, as the foundations of edifices.

103. Pit-sand has a rougher and more angular grain than river or sea sand; and, on this account, is generally preferred by builders for mortar used for brick, or stone-work. Whether it forms a stronger mortar than the other two is not positively settled, although some experiments would lead to the conclusion that it does.

104. River and sea sand are by some preferred for plastering, because they are whiter, and have a finer and more uniform grain than pit sand; but as the sands from the shores of tidal waters contain salts, they should not be used, owing to their hygrometric properties, before the salts are dissolved out in fresh water by careful washing.

105. Pit-sand is seldom obtained free from a mixture of dirt, or clay; and these, when found in any notable quantity in it, give a weak and bad mortar. Earthy sands should, therefore, be cleansed from dirt before using them for mortar; this may be effected by washing the sand in shallow vats, and allowing the turbid water, in which the clay, dust, and other like impurities are held in suspension, to run off.

106. Sand, when pure or well cleansed, may be known by not soiling the fingers when rubbed between them.

107. *Hydraulic mortar.* This material may be made from the natural hydraulic limes; from those which are prepared by M. Vicat's process; or from a mixture of common, or feebly hydraulic lime, with a natural or artificial puzzolana. All writers, however, agree that it is better to use a natural than an artificial hydraulic lime, when the former can be readily procured.

108. When the lime used is strongly hydraulic, M. Vicat is of opinion that sand alone should be used with it, to form a good hydraulic mortar. General Treussart has drawn the conclusion, from his experiments, that the mortar of all hydraulic limes is improved by an addition of a natural or artificial puzzolana. The quantity of sand used may vary from 1½ to 2 parts of the lime in bulk, when reduced to a thick pulp.

109. For hydraulic mortars, made of common, feeble, or or

dinary hydraulic limes, and artificial puzzolana, M. Vicat states that the puzzolana should be the weaker as the lime is more strongly hydraulic; using, for example, a very energetic puzzolana with a fat, or a feebly hydraulic lime. The proportion of sand which can be incorporated with these ingredients, to form an hydraulic mortar, is stated by General Treussart to be one volume to one of puzzolana, and one of lime in paste.

110. In proportioning the ingredients, the object to which the mortar is to be applied should be regarded. When it is to serve to unite stone, or brick work, it is better that the hydraulic lime should be rather in excess; when it is used as a *matrix* for beton, no more lime should be used than is strictly required. No harm will arise from an excess of good hydraulic lime, in any case; but an excess of common lime is injurious to the quality of the mortar.

111. Common and ordinary hydraulic limes, when made into mortar with *arènes*, give a good material for hydraulic purposes. The proportions in which these have been found to succeed well, are one of lime to three of *arènes*.

112. Hydraulic cement, from the promptitude with which it hardens, both in the air and under water, is an invaluable material where this property is essential. Any dose of sand injures its properties as a cement. But hydraulic cement may be added with decided advantage to a mortar of common, or of feebly hydraulic lime and sand. It is in this way that it is generally used in our public works. The French engineers give the preference to a good hydraulic mortar over hydraulic cement, both for uniting stone, or brick work, and for plastering. They find, from their practice, that when used as a stucco, it does not withstand well the effects of weather; that it swells and cracks in time; and, when laid on in successive coats, that they become detached from each other.

General Pasley, who has paid great attention to the properties of natural and artificial hydraulic cements, does not agree with the French engineers in his conclusions. He states that, when skilfully applied, hydraulic cement is superior to any hydraulic mortar for masonry, but that it must be used only in thin joints; and, when applied as a stucco, that it should be laid on in but one coat; or, if it be laid on in two, the second must be added long before the first has set, so that, in fact, the two make but one coat. By attending to these precautions, General Pasley states that a stucco of hydraulic cement and sand will withstand perfectly the effects of frost.

113. *Mortars exposed to weather.* The French engineers, who have paid great attention to the subject of mortars, coincide in the opinion, that a mortar cannot be made of fat lime and any inert sands, like those of the silicious, or calcareous kinds which

will withstand the ordinary exposure of weather; and that, to obtain a good mortar for this purpose, either the hydraulic limes mixed with sand must be employed, or else common lime mixed either with *arènes*, or with a puzzolana and sand.

114. Any pure sand mixed in proper proportions with hydraulic lime, will give a good mortar for the open air; but the hardness of the mortar will be affected by the size of the grain, particularly when hydraulic lime is used. Fine sand yields the best mortar with good hydraulic lime; mixed sand with the feebly hydraulic limes; and coarse sand with fat lime.

115. The proportion which the lime should bear to the sand seems to depend, in some measure, on the manner in which the lime is slaked. M. Vicat states, that the strength of mortar made of a stiff paste of fat lime, slaked in the ordinary way, increases from 0.50 to 2.40 to one of the paste in volume; and that, when the lime is slaked by immersion, one volume of the like paste will give a mortar that increases in strength from 0.50 to 2.20 parts of sand.

For one volume of a paste of hydraulic lime, slaked in the ordinary way, the strength of the mortar increases from 0 to 1.80 parts of sand; and, when slaked by immersion, the mortar of a like paste increases in strength from 0 to 1.70 parts of lime. In every case, when the dose of sand was increased beyond these proportions, the strength of the resulting mortar was found to decrease.

116. *Manipulations of Mortar*. The quality of hydraulic mortar, which is to be immersed in water, is more affected by the manner in which the lime is slaked, and the ingredients mixed, than that of mortar which is to be exposed to the weather; although in both cases the increase of strength, by the best manipulations, is sufficient to make a study of them a matter of some consequence.

117. The results obtained from the ordinary method of slaking, by sprinkling, or by immersion, in the case of good hydraulic limes, are nearly the same. Spontaneous, or air-slaking, gives invariably the worst results. For common and slightly hydraulic lime, M. Vicat states that air-slaking yields the best results, and ordinary slaking the worst.

118. The ingredients of mortar are incorporated either by manual labor, or by machinery: the latter method gives results superior to the former. The machines commonly used for mixing mortar are either the ordinary pug-mill (Fig. 4) employed by brickmakers for tempering clay, or a grinding-mill, (Fig. 5.) The grinding-mill is the best machine, because it not only reduces the lumps, which are found in the most carefully burnt stone, after the slaking is apparently complete, but it brings the

lime to the state of a uniform stiff paste, which it should receive before the sand is incorporated with it. Care should be taken

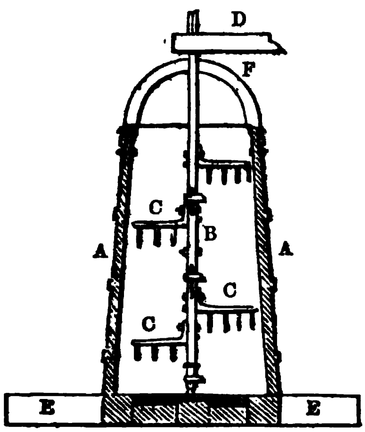


Fig. 4 represents a vertical section through the axis of a pug-mill, for mixing or tempering mortar.—This mill consists of a hooped vessel, of the form of a conical frustum, which receives the ingredients, and a vertical shaft, to which arms with teeth, resembling an ordinary rake, are attached, for the purpose of mixing the ingredients.
A, A, section of sides of the vessel.
B, vertical shaft to which the arms C are affixed.
D, horizontal bar for giving a circular motion to the shaft B.
E, sills of timber supporting the mill.
F, wrought-iron support through which the upper part of the shaft passes.

not to add too much water, particularly when the mortar is to be immersed in water. The mortar-mill, on this account, should be sheltered from rain; and the quantity of water with which it is

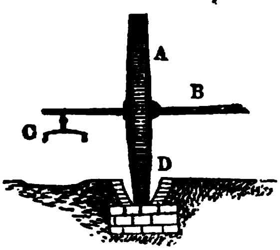


Fig. 5 represents a part of a mill for crushing the lime and tempering the mortar.
A, heavy wheel of timber, or cast iron.
B, horizontal bar passing through the wheel, which at one extremity is fixed to a vertical shaft, and is arranged at the other (C) with the proper gearing for a horse.
D, a circular trough, with a trapezoidal cross section which receives the ingredients to be mixed. The trough may be from 20 to 30 feet in diameter; about 18 inches wide at top, and 12 inches deep; and be built of hard brick, stone, or timber laid on a firm foundation.

supplied may vary with the state of the weather. Nothing seems to be gained by carrying the process of mixing, beyond obtaining a uniform mass of the consistence of plastic clay. Mortars of hydraulic lime are injured by long exposure to the air, and frequent turnings and mixings with a shovel or spade; those of common lime, under like circumstances, seem to be improved. Mortar, which has been set aside for a day or two, will become sensibly firmer; if not allowed to stand too long, it may be again reduced to its clayey consistence, by simply pounding it with a beetle, without any fresh addition of water.

119. *Setting and Durability of Mortars.* Mortar of common lime, without any addition of puzzolana, will not set in humid situations, like the foundations of edifices, until after a very long lapse of time. They set very soon when exposed to the air, or to an atmosphere of carbonic acid gas. If, after having become

hard in the open air, they are placed under water, they in time lose their cohesion and fall to pieces.

120. Common mortars, which have had time to harden, resist the action of severe frosts very well, if they are made rather *poor*, or with an excess of sand. The sand should be over 2.40 parts, in bulk, to one volume of the lime in paste; and coarse sand is found to give better results than fine sand.

121. Good hydraulic mortars set equally well in damp situations, and in the open air; and those which have hardened in the air will retain their hardness when immersed in water. They also resist well the action of frost, if they have had time to set before exposure to it; but, like common mortars, they require to be made with an excess of sand, to withstand well atmospheric changes.

122. The surface of a mass of hydraulic mortar, whether made of a natural hydraulic lime or otherwise, when immersed in water, becomes more or less degraded by the action of the water upon the lime, particularly in a current. When the water is stagnant, a very thin crust of carbonate of lime forms on the surface of the mass, owing to the absorption by the lime of the carbonic acid gas in the water. This crust, if the water be not agitated, will preserve the soft mortar beneath it from the farther action of the water, until it has had time to become hard, when the water will no longer act upon the lime in any perceptible degree.

123. Hydraulic mortars set with more or less promptness, according to the character of the hydraulic lime, or of the puzzolana which enters into their composition. Artificial hydraulic mortars, with an excess of lime, set more slowly than when the lime is in a just proportion to the other ingredients.

124. The quick-setting hydraulic limes are said to furnish a mortar which, in time, acquires neither as much strength nor hardness as that from the slower-setting hydraulic limes. Artificial hydraulic mortars, on the contrary, which set quickly, gain, in time, more strength and hardness than those which set slowly.

125. The time in which hydraulic mortars, immersed in water, attain their greatest hardness, is not well ascertained. Mortars made of strong hydraulic limes do not show any appreciable increase of hardness after the second year of their immersion; while the best artificial hydraulic mortars continue to harden, in a sensible degree, during the third year after their immersion.

126. *Theory of Mortars.* The paste of a hydrate, either of common or of hydraulic lime, when exposed to the air, absorbs carbonic acid gas from it; passes to the state of sub-carbonate of lime; without, however, rejecting the water of the hydrate, and gradually hardens. The time required for the complete satura

ucn of the mass exposed, will depend on its bulk. The absorption of the gas commences at the surface and proceeds more slowly towards the centre. The hardening of mortars exposed to the atmosphere, is generally attributed to this absorption of the gas, as no chemical action of lime upon quartzose sand, which is the usual kind employed for mortars, has hitherto been detected by the most careful experiments.

127. With regard to hydraulic mortars, it is difficult to account for their hardening, except upon the effect which the silicate of lime may have upon the excess of simple hydrate of uncombined lime contained in the mass. M. Petot supposes, that the particles of silicate of lime form so many centres, around which the uncombined hydrates group themselves in a crystalline form; becoming thus sufficiently hard to resist the solvent action of water. With respect to the action of quartzose sand in hydraulic mortars, M. Petot thinks that the grains produce the same mechanical effect as the particles of the silicate of lime, in inducing the aggregation of the uncombined hydrate.

128. *Concrete.* This term is applied, by English architects and engineers, to a mortar of finely-pulverized quick-lime, sand, and gravel. These materials are first thoroughly mixed in a dry state, sufficient water is added to bring the mass to the ordinary consistence of mortar, and it is then rapidly worked up by a shovel, or else passed through a pug-mill. The concrete is used immediately after the materials are well incorporated, and while the mass is hot.

129. The materials for concrete are compounded in various proportions. The most approved are those in which the lime and sand are in the proper proportions to form a good mortar and the gravel is twice the bulk of the sand. The gravel used should be clean, and any pebbles contained in it larger than an egg, should be broken up before the materials are incorporated.

130. Hot water has in some cases been used in making con crete. It causes the mass to set more rapidly, but is not otherwise of any advantage.

131. The bulk of a mass of concrete, when first made, is found to be about one fifth less than the total bulk of the dry materials But, as the lime slakes, the mass of concrete is found to expand about three eighths of an inch in height, for every foot of the mass in depth.

132. The use of concrete is at present mostly restricted to forming a solid bed, in bad soils, for the foundations of edifices. It has also been used to form blocks of artificial stone, for the walls of buildings and other like purposes; but experience has shown, that it possesses neither the durability nor strength requi

site for structures of a permanent character, when exposed to the action of water, or of the weather.

133. *Beton*. The term beton is applied, by French engineers to any mixture of hydraulic mortar with fragments of brick, stone or gravel; and it is now also used by English engineers in the same sense.

134. The proportions of the ingredients used for beton are variously stated by different authors. The sole object for which the gravel, or the broken stone is used, being to obtain a more economical material than a like mass of hydraulic mortar alone would yield, the quantity of broken stone should be as great as can be thoroughly united by the mortar. The smallest amount of mortar, therefore, that can be used for this purpose, will be that which will be just equal in volume to the void spaces in any given bulk of the broken stone, or gravel. The proportion which the volume occupied by the void spaces bears to any bulk of a loose material, like broken stone, or gravel, may be readily ascertained by filling a vessel of known capacity with the loose material, and pouring in as much water as the vessel will contain. The volume of water thus found, will be the same as that of the void spaces.

135. Beton made of mortar and broken stone, in which the proportions of the ingredients were ascertained by the process just detailed, has been found to give satisfactory results; but, in order to obviate any defect arising from imperfect manipulation, it is usual to add an excess of mortar above that of the void spaces.

The best and most economical beton is made of a mixture of broken stone, or brick, in fragments not larger than a hen's egg, and of coarse and fine gravel mixed in suitable proportions.

136. In making beton, the mortar is first prepared, and then incorporated with the finer gravel; the resulting mixture is spread out into a cake, 4 or 6 inches in thickness, over which the coarser gravel and broken stone are uniformly strewed and pressed down, the whole mass being finally brought to a homogeneous state with the hoe and shovel.

Beton is used for the same purposes as concrete, to which it is superior in every respect, but particularly so for foundations laid under water, or in humid localities.

137. *Adherence of Mortar.* The force with which mortars in general adhere to other materials, depends on the nature of the material, its texture, and the state of the surface to which the mortar is applied.

138. Mortar adheres most strongly to brick; and more feebly to wood than to any other material. Among stones, its adhesion to lime-stone is generally greatest; and to basalt and sand-stones,

least. Among stones of the same class, it adheres generally better to the porous and coarse-grained, than to the compact and fine-grained. Among surfaces, it adheres more strongly to the rough than to the smooth.

139. The adhesion of common mortar to brick and stone, for the first few years, is greater than the cohesion of its own particles. The force with which hydraulic cement adheres to the same materials, is less than that of the cohesion between its own particles: and from some recent experiments of Colonel Pasley, on this subject, it would seem that hydraulic cement adheres with nearly the same force to polished surfaces of stone as to rough surfaces.

140. From experiments made by Rondelet, on the adhesion of common mortar to stone, it appears that it required a force varying from 15 to 30 pounds on the square inch, applied perpendicular to the plane of the joint, to separate the mortar and stone after six months union; whereas, only 5 pounds to the square inch was required to separate the same surfaces, when applied parallel to the plane of the joint.

From experiments made by Colonel Pasley, he concludes that the adhesive force of hydraulic cement to stone, may be taken as high as 125 pounds on the square inch, when the joint has had time to harden throughout; but, he remarks, that as in large joints the exterior part of the joint may have hardened while the interior still remains soft, it is not safe to estimate the adhesive force, in such cases, higher than from 30 to 40 pounds on the square inch.

MASTICS.

141. The term *Mastic* is generally applied to artificial or natural combinations of bituminous or resinous substances with other ingredients. They are converted to various uses in constructions, either as cements for other materials, or as coatings, to render them impervious to water.

142. *Bituminous Mastic.* The knowledge of this material dates back to an early period; but it is only within, comparatively speaking, a few years that it has come into common use in Europe and this country. The most usual form in which it is now employed, is a combination of mineral tar and powdered bituminous lime-stone.

143. The localities of each of these substances are very numerous; but they are chiefly brought into the market from several places in Switzerland and France, where these minerals are found in great abundance; the most noted being Val-de-Travers in Switzerland, and Seyssel in France.

144. The mineral tar is usually obtained by boiling in water a

soft sand-stone, called by the French *molasse*, which is strongly impregnated with the tar. In this process, the tar is disengaged and rises to the surface of the water, or adheres to the sides of the vessel, and the earthy matter remains at the bottom. An analysis of a rich specimen of the Seyssel bituminous sand-stone gave the following results:—

Bituminous oil	.086	Bitumen	.106
Carbon	.020		
Quartzy grains			.690
Calcareous grains			.204
			1.000

145. The bituminous lime-stone which, when reduced to a powdered state, is mixed with the mineral tar, is known at the localities mentioned by the name of *asphaltum*, an appellation which is now usually given to the mastic. This lime-stone occurs in the secondary formations, and is found to contain various proportions of bitumen, varying mostly from 3 to 15 per cent., with the other ordinary minerals, as argile, &c., which are met with in this formation.

146. The bituminous mastic is prepared from these two materials by heating the mineral tar in cast-iron or sheet-iron boilers, and stirring in the proper proportion of the powdered lime-stone. This operation, although very simple in its kind, requires great attention and skill on the part of the workmen in managing the fire, as the mastic may be injured by too low, or too high a degree of heat. The best plan appears to be, to apply a brisk fire until the boiling liquid commences to give out a thin whitish vapor. The fire is then moderated and kept at a uniform state, and the powdered stone is gradually added, and mixed in with the tar by stirring the two well together. When the temperature has been raised too high, the heated mass gives out a yellowish or brownish vapor. In this state it should be stirred rapidly, and be removed at once from the fire.

147. The asphaltic stone may be reduced to powder, either by roasting it in vessels over a fire, or by grinding it down in the ordinary mortar-mill. For roasting, the stone is first reduced to fragments the size of an egg. These fragments are put into an iron vessel; heat is applied, and the stone is reduced to powder by stirring it and breaking it up with an iron instrument. This process is not only less economical than grinding, but the material loses a portion of its tar from evaporation, besides being liable to injury from too great a degree of heat. For grinding, the stone is first broken as for roasting. Care should be taken, during the process, to stir the mass frequently, otherwise it may

form into a cake. Cold dry weather is the best season for this operation; the stone, however, should not be exposed to the weather.

148. Owing to the variable quantity of mineral tar in bituminous lime-stone, the best proportions of the tar and powdered stone for bituminous mastic, cannot be assigned beforehand. Three or four per cent. too much of tar, is said to impair both the durability and tenacity of the mastic; while too small a quantity is equally prejudicial. Generally, from eight to ten per cent. of the tar, by weight, has been found to yield a favorable result.

149. Mastics have been formed by mixing vegetable tar, pitch, and other resinous substances, with litharge, powdered brick, powdered lime-stone, &c.; but the results obtained have generally been inferior to those from bituminous mastic.

150. Mineral tar is more durable than vegetable tar, and on this account it has been used alone as a coating for other materials, but not with the same success as mastic. Employed in this way the tar in time becomes dry and peels off; whereas, in the form of mastic, the hard matter with which it is mixed prevents the evaporation of the oily portion of the tar, and thus promotes its durability.

151. The uses to which bituminous mastic is applied are daily increasing. It has been used for paving in a variety of forms either as a cement for large blocks of stone, or as the *matrix* of a concrete formed of small fragments of stone or gravel; as a pointing, it is found to be more serviceable, for some purposes, than hydraulic cement; it forms one of the best water-tight coatings for cisterns, cellars, the cappings of arches, terraces, and other similar roofings now in use; and is a good preservative agent for wood work exposed to wet or damp.

GLUE.

152. The common animal glue is seldom used as a cement for any other purpose than for the work of the joiner. Although of considerable tenacity, it is weak, brittle, and readily impaired by moisture.

153. Within a few years back, a material termed *marine glue*, the invention of Mr. Jeffery of England, has attracted attention in England and France, in both which countries its qualities as a cement, both for stone and wood, have been tested with the most satisfactory results. This composition is said to be made by first dissolving caoutchouc in coal naphtha, in the proportion of one pound of the former to five gallons of the latter; to this solution an equal weight of shellac is added, and the composition is then placed over a fire and thoroughly mixed by stirring

154. Owing to its insolubility in water, its remarkable tenacity and adhesion, and its powers of contraction and expansion through a very considerable range of temperature, without becoming either very soft or brittle, the marine glue promises to be not only a valuable addition to the resources of the naval architect, but to the civil engineer.

BRICK.

155. This material is properly an artificial stone, formed by submitting common clay, which has undergone suitable preparation, to a temperature sufficient to convert it into a semi-vitrified state.

156. Brick may be used for nearly all the purposes to which stone is applicable; for when carefully made, its strength, hardness, and durability, are but little inferior to the more ordinary kinds of building stone. It remains unchanged under the extremes of temperature; resists the action of water; sets firmly and promptly with mortar; and being both cheaper and lighter than stone, is preferable to it for many kinds of structures, as arches, the walls of houses, &c.

157. The art of brick-making is a distinct branch of the useful arts, and does not properly belong to that of the engineer. But as the engineer is frequently obliged to prepare this material himself, the following outline of the process may prove of service.

158. The best brick earth is composed of a mixture of pure clay and sand, deprived of pebbles of every kind, but particularly of those which contain lime, and pyritous, or other metallic substances; as these substances, when in large quantities, and in the form of pebbles, act as fluxes, and destroy the shape of the brick, and weaken it by causing cavities and cracks; but in small quantities, and equally diffused throughout the earth, they assist the vitrification, and give it a more uniform character.

159. Good brick earth is frequently found in a natural state, and requires no other preparation for the purposes of the brickmaker. When he is obliged to prepare the earth by mixing the pure clay and sand, direct experiments should, in all cases, be made, to ascertain the proper proportions of the two. If the clay is in excess, the temperature required to semi-vitrify it, will cause it to warp, shrink, and crack; and, if there is an excess of sand, complete vitrification will ensue, under similar circumstances.

160. The quality of the brick depends as much on the care bestowed on its manufacture, as on the quality of the earth. The first stage of the process is to free the earth from pebbles, which is most effectually done by digging it out early in the autumn, and exposing it in small heaps to the weather during the winter. In the spring, the heaps are carefully riddled, if necessary, and

the earth is then in a proper state to be kneaded or tempered. The quantity of water required in tempering, will depend on the quality of the earth; no more should be used, than will be sufficient to make the earth so plastic, as to admit of its being easily moulded by the workman. About half a cubic foot of water to one of the earth is, in most cases, a good proportion. If too much water be used, the brick will not only be very slow in drying, but it will, in most cases, crack, owing to the surface becoming completely dry, before the moisture of the interior has had time to escape; the consequence of which will be, that the brick, when burnt, will be either entirely unfit for use, or very weak.

161. Machinery is now coming into very general use in moulding brick: it is superior to manual labor, not only from the labor saved, but from its yielding a better quality of brick, by giving it great density, which adds to its strength.

162. Great attention is requisite in drying the brick before it urned. It should be placed, for this purpose, in a dry exposure, and be sheltered from the direct action of the wind and sun, in order that the moisture may be carried off slowly and uniformly from the entire surface. When this precaution is not taken, the brick will generally crack from the unequal shrinking, arising from one part drying more rapidly than the rest.

163. The burning and cooling should be done with equal care. A very moderate fire should be applied under the arches of the kiln for about twenty-four hours, to expel any remaining moisture from the raw brick; this is known to be completely effected, when the smoke from the kiln is no longer black. The fire is then increased until the bricks of the arches attain a white heat; it is then allowed to abate in some degree, in order to prevent complete vitrification; and it is alternately raised and lowered in this way, until the burning is complete, which may be ascertained by examining the bricks at the top of the kiln. The cooling should be slowly effected; otherwise the bricks will not withstand the effects of the weather. It is done by closing the mouths of the arches, and the top and sides of the kiln in the most effectual manner with moist clay and burnt brick, and allowing the kiln to remain in this state until the warmth has subsided.

164. Brick of a good quality exhibits a fine, compact, uniform texture, when broken across; gives a clear ringing sound, when struck; and is of a cherry red, or brownish color. Three varieties are found in the kiln; those which form the arches, denominated *arch brick*, are always vitrified in part, and present a grayish glassy appearance at one end; they are very hard, but brittle, of inferior strength, and set badly with mortar; those from the interior of the kiln, usually denominated *body*, *hard*, or *cherry*

brick, are of the best quality; those from near the top and sides, are generally underburnt, and are denominated *soft*, *pale*, or *sammel brick;* they have neither sufficient strength, nor durability for heavy masonry, nor the outside courses of walls, which are exposed to the weather.

165. The quality of good brick may be improved by soaking it for some days in water, and re-burning it. This process increases both the strength and durability, and renders the brick more suitable for hydraulic constructions, as it is found not to imbibe water so readily after having undergone it.

166. The size and form of bricks present but trifling variations. They are generally rectangular parallelopipeds, from eight to nine inches long, from four to four and a half wide, and from two to two and a quarter thick. Thin brick is generally of a better quality than thick, because it can be dried and burned more uniformly.

167. *Fire-brick*. This material is used for the facing of furnaces, fireplaces, &c., where a high degree of temperature is to be sustained. It is made of a very refractory kind of pure clay, that remains unchanged by a degree of heat which would vitrify and completely destroy ordinary brick. A very remarkable brick of this character has been made of *agaric mineral;* it remains unchanged under the highest temperature, is one of the worst conductors of heat, and so light that it will float on water.

168. *Tiles*. As a roof covering, tiles are, in many respects, superior to slate, or metallic coverings. They are strong and durable, and are very suitable for the covering of arches, as their great weight is not so objectionable here, as in the case of roofs formed of frames of timber.

Tiles should be made of the best potter's clay, and be moulded with great care to give them the greatest density and strength. They are of very variable form and size; the worst being the flat square form, as, from the liability of the clay to warp in burning, they do not make a perfectly water-tight covering.

WOOD.

169. This material holds the next rank to stone, owing to its durability and strength, and the very general use made of it in constructions. To suit it to the purposes of the engineer, the tree is felled after having attained its mature growth, and the trunk, the larger branches that spring from the trunk, and the main parts of the root, are cut into suitable dimensions, and seasoned, in which state, the term *timber* is applied to it. The crooked, or *compass* timber of the branches and roots, is mostly applied to the purposes of ship-building, for the knees and other

parts of the frame-work of vessels, requiring crooked timber The trunk furnishes all the straight timber.

170. The trunk of a full-grown tree presents three distinct parts: the *bark*, which forms the exterior coating; the *sap-wood*, which is next to the bark; the *heart*, or inner part, which is easily distinguishable from the sap-wood by its greater firmness and darker color.

171. The heart forms the essential part of the trunk, as a building material. The sap-wood possesses but little strength and is subject to rapid decay, owing to the great quantity of fermentable matter contained in it; and the bark is not only without strength, but, if suffered to remain on the tree after it is felled, it hastens the decay of the sap-wood and heart.

172. Trees should not be felled for timber until they have attained their mature growth, nor after they exhibit symptoms of decline; otherwise, the timber will be less strong, and far less durable. Most forest trees arrive at maturity between fifty and one hundred years, and commence to decline after one hundred and fifty or two hundred years. The age of the tree can, in most cases, be ascertained either by its external appearances, or by cutting into the centre of the trunk, and counting the rings, or layers of the sap and heart, as a new ring is formed each year in the process of vegetation. When the tree commences to decline, the extremities of the old branches, and particularly the top, exhibit signs of decay.

173. Trees should not be felled while the sap is in circulation; for this substance is of a peculiarly fermentable nature, and, therefore, very productive of destruction to the wood. The winter months, and July, are the seasons in which trees are felled for timber, as the sap is generally considered as dormant during these months; this practice, however, is in part condemned by some writers; and the recent experiments of M. Boucherie, in France, support this opinion, and indicate midsummer and autumn as the seasons in which the sap is least active, and therefore as most favorable for felling.

174. As the sap-wood, in most trees, forms a large portion of the trunk, experiments have been made, for the purpose of improving its strength and durability. These experiments have been mostly directed towards the manner of preparing the tree, before felling it. One method consists in *girdling*, or making an incision with an axe around the trunk, completely through the sap-wood, and suffering the tree to stand in this state until it is dead; the other consists in *barking*, or stripping the entire trunk of its bark, without wounding the sap-wood, early in the spring, and allowing the tree to stand until the new leaves have put forth and fallen, before it is felled. The sap-wood of trees, treated by both

of these methods, was found very much improved in hardness strength, and durability; the results from girdling were, however inferior to those from barking.

175. The seasoning of timber is of the greatest importance, not only to its durability, but to the solidity of the structure for which it may be used; as a very slight shrinking of some of the pieces, arising from the seasoning of the wood, might, in many cases, cause material injury, if not complete destruction to the structure. Timber is considered as sufficiently seasoned, for the purposes of frame-work, when it has lost about one fifth of the weight which it has in a green state. Several methods are in use for seasoning timber: they consist either in an exposure to the air for a certain period in a sheltered position, which is termed *natural seasoning*; in immersion in water, termed *water seasoning*; or in boiling, or *steaming*.

176. For natural seasoning, it is usually recommended to strip the trunk of its branches and bark, immediately upon felling, and to remove it to some dry position, until it can be sawed into suitable scantling. From the experiments of M. Boucherie, just cited, it would seem that better results would ensue, from allowing the branches and bark to remain on the trunk for some days after felling. In this state, the vital action of the tree continuing in operation, the sap-vessels will be gradually exhausted of sap, and filled with air, and the trunk thus better prepared for the process of seasoning. To complete the seasoning, the sawed timber should be piled under drying sheds, where it will be freely exposed to the circulation of the air, but sheltered from the direct action of the wind, rain, and sun. By taking these precautions, an equable evaporation of the moisture will take place over the entire surface, which will prevent either warping or splitting, which necessarily ensues when one part dries more rapidly than another. It is farther recommended, instead of piling the pieces on each other in a horizontal position, that they be laid on cast-iron supports properly prepared, and with a sufficient inclination to facilitate the dripping of the sap from one end; and that heavy round timber be bored through the centre, to expose a greater surface to the air, as it has been found that it cracks more in seasoning than square timber.

Natural seasoning is preferable to any other, as timber seasoned in this way is both stronger and more durable than when prepared by any artificial process. Most timber will require, on an average, about two years to become fully seasoned in the natural way.

177. The process of seasoning by immersion in water, is slow and imperfect, as it takes years to saturate heavy timber; and the soluble matter is discharged very slowly, and chiefly from the

exterior layers of the immersed wood. The practice of keeping timber in water, with a view to facilitate its seasoning, has been condemned as of doubtful utility; particularly immersion in salt water, where the timber is liable to the inroads of those two very destructive inhabitants of our waters, the *Limnoria Terebrans*, and *Teredo Navalis;* the former of which rapidly destroys the heaviest logs, by gradually eating in between the annual rings; and the latter, the well-known *ship-worm*, by converting timber into a perfect honeycomb state by its numerous perforations.

178 Steaming is mostly in use for ship-building, where it is necessary to soften the fibres, for the purpose of bending large pieces of timber. This is effected by placing the timber in strong steam-tight cylinders, where it is subjected to the action of steam long enough for the object in view; the period usually allowed, is one hour to each inch in thickness. Steaming slightly impairs the strength of timber, but renders it less subject to decay, and less liable to warp and crack.

179. When timber is used for posts partly imbedded in the ground, it is usual to char the part imbedded, to preserve it from decay. This method is only serviceable when the timber has been previously well seasoned; but for green timber it is highly injurious, as by closing the pores, it prevents the evaporation from the surface, and thus causes fermentation and rapid decay within.

180. The most durable timber is procured from trees of a close compact texture, which, on analysis, yield the largest quantity of carbon. And those which grow in moist and shady localities, furnish timber which is weaker and less durable than that from trees growing in a dry open exposure.

181. Timber is subject to defects, arising either from some peculiarity in the growth of the tree, or from the effects of the weather. Straight-grained timber, free from knots, is superior in strength and quality, as a building material, to that which is the reverse.

182. The action of high winds, or of severe frosts, injures the tree while standing: the former separating the layers from each other, forming what is denominated *rolled timber;* the latter cracking the timber in several places, from the surface to the centre. These defects, as well as those arising from worms, or age, are easily seen by examining a cross section of the trunk.

183. The *wet* and *dry rot* are the most serious causes of the decay of timber; as all the remedies thus far proposed to prevent them, are too expensive to admit of a very general application. Both of these causes have the same origin, fermentation, and consequent putrefaction. The wet rot takes place in wood exposed, alternately, to moisture and dryness; and the dry rot is occasioned by want of a free circulation of air, as in confined

warm localities, like cellars and the more confined parts of vessels.

Trees of rapid growth, which contain a arge portion of sap-wood, and timber of every description, wher used green, where there is a want of a free circulation of air, decay very rapidly with the rot.

184. Numberless experiments have been made on the preservation of timber, and many processes for this purpose have been patented both in Europe and this country. Several of these processes have yielded the most satisfactory results; and nearly all have proved more or less efficacious. The means mostly resorted to have been the saturation of the timber in the solution of some salt with a metallic, or earthy base, thus forming an insoluble compound with the soluble matter of the timber. The salts which have been most generally tried, are the sulphate of iron, or copper, and the chloride of mercury, zinc, or calcium The results obtained from the chlorides have been more satisfactory than those from the sulphates; the latter class of salts with metallic bases possess undoubted antiseptic properties; but it is stated that the freed sulphuric acid, arising from the chemical action of the salt on the wood, impairs the woody fibre, and changes it into a substance resembling carbon.

185. The processes which have come into most general use, are those of Mr. Kyan, and of Sir W. Burnett, called after the patentees *kyanizing* and *burnetizing*. Kyan's process is to saturate the timber with a solution of chloride of mercury; using, for the solution, one pound of the salt to five gallons of water Burnett uses a solution of chloride of zinc, in the proportion of one pound of the salt to ten gallons of water, for common purposes; and a more highly concentrated solution when the object is also to render the wood incombustible.

186. As timber under the ordinary circumstances of immersion imbibes the solutions very slowly, a more expeditious, as well as more perfect means of saturation has been used of late, which consists in placing the wood to be prepared in strong wrought-iron cylinders, lined with felt and boards, to protect the iron from the action of the solution, where, first by exhausting the cylinders of air, and then applying a strong pressure by means of a force-pump, the liquid is forced into the sap and air-vessels, and penetrates to the very centre of the timber.

187. Among the patented processes in our country, that of Mr. Earle has received most notice. This consists in boiling the timber in a solution of the sulphates of copper and iron. Opinion seems to be divided as to the efficacy of this method. It has been tried for the preservation of timber for artillery carriages, but not with satisfactory results

188. M. Boucherie, to whose able researches on this subject reference has been made, noticing the slowness with which aqueous solutions were imbibed by wood, when simply immersed in them, conceived the ingenious idea of rendering the vital action of the sap-vessels subservient to a thorough impregnation of every part of the trunk where there was this vitality. To effect this, he first immersed the butt end of a freshly-felled tree in a liquid, and found that it was diffused throughout all parts of the tree, in a few days, by the action in question. But, finding it difficult to manage trees of some size when felled, M. Boucherie next attempted to saturate them before felling; for which purpose he bored an auger-hole through the trunk, and made a saw-cut from the auger-hole outwards, on each side, to within a few inches of the exterior, leaving enough of the fibres untouched to support the tree. One end of the auger-hole was then stopped, as well as all of the saw-cut on the exterior, and the liquid was introduced by a tube inserted into the open end of the auger-hole. This method was found equally efficacious with the first, and more convenient.

189. After examining the action of the various neutral salts on the soluble matter contained in wood, M. Boucherie was led to try the impure pyrolignite of iron, both from its chemical composition and its cheapness. The results of this experiment were perfectly satisfactory. The pyrolignite of iron, in the proportion of one fiftieth in weight of the green wood, was found not only to preserve the wood from decay, but to harden it to a very high degree.

190. Observing that the pliability and elasticity of wood depended, in a great measure, on the moisture contained in it, M. Boucherie next directed his attention to the means of improving these properties. For this purpose, he tried solutions of various deliquescent salts, which were found to answer the end proposed. Among these solutions, he gives the preference to that of chloride of calcium, which also, when concentrated, renders the wood incombustible. He also recommends for like purposes the mother water of salt-marshes, as cheaper than the solution of the chloride of calcium. Timber prepared in this way is not only improved in elasticity and pliability, but is prevented from warping and cracking; the timber, however, is subject to greater variations in weight than when seasoned naturally.

191. M. Boucherie is of opinion that the earthy chlorides will also act as preservatives, but to ensure this he recommends that they be mixed with one fifth of pyrolignite of iron.

192. From other experiments of M. Boucherie, it appears that the sap may be expelled from any freshly-felled timber by the pressure of a liquid, and the timber be impregnated as thoroughly

as by the preceding processes. To effect this, the piece to be saturated is placed in an upright position, so that the sap may flow readily from the lower end; a water-tight bag, containing the liquid, is affixed to the upper extremity which is surmounted by the liquid, the pressure from which expels the sap, and fills the sap-vessels with the liquid. The process is complete when the liquid is found to issue in a pure state from the lower end of the stick.

193. Either of the above processes may be applied in impregnating timber with coloring matter for ornamental purposes. The plan recommended by M. Boucherie, consists in introducing separately the solutions by the chemical union of which the color is to be formed.

194. The effect of time on the durability of timber, prepared by any of the various chemical processes which have just been detailed, remains to be seen; although results of the most satisfactory nature may be looked for, considering the severe tests to which most of them have been submitted, by exposure in situations peculiarly favorable to the destruction of ligneous substances.

195. The durability of timber, when not prepared by any of the above-mentioned processes, varies greatly under different circumstances of exposure. If placed in a sheltered position, and exposed to a free circulation of air, timber will last for centuries, without showing any sensible changes in its physical properties. An equal, if not superior, durability is observed when it is immersed in fresh water, or embedded in thick walls, or under ground, so as to be beyond the influence of atmospheric changes.

196. In salt water, however, particularly in warm climates, timber is rapidly destroyed by the two animals already noticed: the one, the *limnoria terebrans*, attacking, it is said, only stationary wood, while the attacks of the other, the *teredo navalis*, are general. Various means have been tried to guard against the ravages of these destructive agents; that of sheathing exposed timber with copper, or with a coating of hydraulic cement, affixed to the wood by studding it thickly over with broad-headed nails to give a hold to the cement, has met with full success; but the oxidation of the metal, and the liability to accident of the cement, limit their efficacy to cases where they can be renewed. The chemical processes for preserving timber from decay, do not appear to guard them in salt water. A process, however, of preserving timber by impregnating it with coal tar, patented in this country by Professor Renwick, appears, from careful experiments, also to be efficacious against the attack of the ship-worm. A coating of Jeffery's marine glue, when impregnated with some

of the insoluble mineral poisons destructive to animal life, is said to subserve the same end.

197. The best seasoned timber will not withstand the effects of exposure to the weather for a much greater period than twenty five years, unless it is protected by a coating of paint or pitch, or of oil laid on hot, when the timber is partly charred over a light blaze. These substances themselves, being of a perishable nature, require to be renewed, from time to time, and will, therefore, be serviceable only in situations which admit of their renewal. They are, moreover, more hurtful than serviceable, to unseasoned timber, as by closing the pores of the exterior surface, they prevent the moisture from escaping from within, and, therefore, promote one of the chief causes of decay.

198. The forests of our own country produce a great variety of the best timber for every purpose, and supply abundantly both our own and foreign markets. The following genera are in most common use.

199. *Oak.* About forty-four species of this tree are enumerated by botanists, as found in our forests, and those of Mexico. The most of them afford a good building material, except the varieties of red oak, the timber of which is weak, and decays rapidly.

The White Oak, (*Quercus Alba,*) so named from the color of its bark, is among the most valuable of the species, and is in very general use, but is mostly reserved for naval constructions; its trunk, which is large, serving for heavy frame-work, and the roots and larger branches affording the best compass timber. The wood is strong and durable, and of a slightly reddish tinge; it is not suitable for boards, as it shrinks about $\frac{1}{32}$ in seasoning, and is very subject to warp and crack.

This tree is found most abundantly in the Middle States. It is seldom seen, in comparison with other forest trees, in the Eastern and Southern States, or in the rich valleys of the Western States.

Post Oak, (*Quercus Obtusiloba.*) This tree seldom attains a greater diameter than about fifteen inches, and, on this account, is mostly used for posts, from which use it takes its name. The wood has a yellowish hue, and close grain; is said to exceed white oak in strength and durability; and is, therefore, an excellent building material for the lighter kinds of frame-work. This tree is found most abundantly in the forests of Maryland and Virginia, and is there frequently called *Box White Oak,* and *Iron Oak.* It also grows in the forests of the Southern and Western States, but is rarely seen farther north than the mouth of the Hudson River.

Chesnut White Oak, (*Quercus Prinus Palustris.*) The tim

oer of this tree s strong and durable, but inferior to the two preceding species. The tree is abundant from North Carolina to Florida.

Rock Chesnu Oak, (*Quercus Prinus Monticola.*) The timber of this tree is mostly in use for naval constructions, for which it is esteemed inferior only to the white oak. The tree is found in the Middle States, and as far north as Vermont.

Live Oak, (*Quercus Virens.*) The wood of this tree is of a yellowish tinge; it is heavy, compact, and of a fine grain; it is stronger and more durable than any other species, and, on this account, it is considered invaluable for the purposes of ship building, for which it is exclusively reserved.

The live oak is not found farther north than the neighborhood of Norfolk, Virginia, nor farther inland, than from fifteen to twenty miles from the seacoast. It is found in abundance along the coast south, and in the adjacent islands as far as the mouth of the Mississippi.

200. *Pine.* This very interesting genus is considered inferior only to the oak, from the excellent timber afforded by nearly all of its species. It is regarded as a most valuable building material, owing to its strength and durability, the straightness of its fibre, the ease with which it is wrought, and its applicability to all the purposes of constructions in wood.

Yellow Pine, (*Pinus Mitis.*) The heart-wood of this tree is fine-grained, moderately resinous, strong, and durable; but the sap-wood is very inferior, decaying rapidly on exposure to the weather. The timber is in very general use for frame-work, &c.

This tree is found throughout our country, but in the greatest abundance in the Middle States. In the Southern States, it is known as *Spruce Pine* and *Short-leaved Pine.*

Long-leaved Pine, or Southern Pine, (*Pinus Australis.*) This tree has but little sap-wood: and the resinous matter is uniformly distributed throughout the heart-wood, which presents a fine compact grain, having more hardness, strength, and durability, than any other species of the pine, owing to which qualities the timber is in very great demand.

The tree is first met with near Norfolk, Virginia, and from this point south, it is abundantly found.

White Pine, or Northern Pine, (*Pinus Strobus.*) This tree takes its name from the color of its wood, which is white, soft light, straight-grained, and durable. It is inferior in strength to the species just described, and has, moreover, the defect of swelling in damp weather. Its timber is, however, in great demand as a good building material. being almost the only kind in use in the Eastern and Northern States, for the frame-wark and joinery of houses, &c.

The finest specimens of this tree grow in the forests of Maine. It is found in great abundance between the 43d and 47th parallels, N. L.

201. Among the forest trees in less general use than the oak and pine, the *Locust*, the *Chesnut*, the *Red Cedar*, and the *Larch*, hold the first place for hardness, strength, and durability. They are chiefly used for the frame-work of vessels. The chesnut, the locust, and the cedar, are preferred to all other trees for posts.

202. The Black, or Double Spruce, (*Abies Nigra*,) also affords an excellent material, its timber being strong, durable, and light.

203. The *Juniper* or *White Cedar*, and the *Cypress*, are very celebrated for affording a material, which is very light, and of great durability, when exposed to the weather; owing to these qualities, it is almost exclusively used for shingles and other exterior coverings. These two trees are found, in great abundance, in the swamps of the Southern States.

METALS.

204. The metals in most common use in constructions are *Iron*, *Copper*, *Zinc*, *Tin*, and *Lead*.

IRON.

205. This metal is very extensively used for the purposes of the engineer and architect, both in the state of *Cast Iron*, and *Wrought Iron*.

206. *Cast Iron* is one of the most valuable building materials, owing to its great strength, hardness, and durability, and the ease with which it can be cast, or moulded, into the best forms, for the purposes to which it is to be applied.

207. Cast iron is divided into two principal varieties, the *Gray cast iron*, and *White cast iron*. There exists a very marked difference between the properties of these two varieties. There are, besides, many intermediate varieties, which partake more or less of the properties of these two, as they approach, in their external appearances, nearer to the one or the other.

208. Gray cast iron, when of a good quality, is slightly malleable in a cold state, and will yield readily to the action of the file, when the hard outside coating is removed. This variety is also sometimes termed soft gray cast iron; it is softer and tougher than the white iron. When broken, the surface of the fracture presents a granular structure; the color is gray; and the lustre is what is termed metallic, resembling small brilliant particles of lead strewed over the surface.

209. White cast iron is very hard and brittle; when recently

broken, the surface of the fracture presents a distinctly-marked crystalline structure; the color is white; and lustre vitreous, or bearing a resemblance to the reflected light from an aggregation of small crystals.

210. Mr. Mallet, in a very able Report made to the British Association for the Advancement of Science, remarking on the great want of uniformity, among manufacturers of iron, in the terms used to describe its different varieties, proposes the following nomenclature, as comprising every variety, with their distinctive characters.

Silvery. Least fusible; thickens rapidly when fluid by a spontaneous puddling; crystals vesicular, often crystalline; incapable of being cut by chisel or file; ultimate cohesion a maximum; elastic range a minimum.

Micaceous. Very soft; greasy feel; peculiar micaceous appearance generally owing to excess of manganese; soils the fingers strongly; crystals large; runs very fluid; contraction large.

Mottled. Tough and hard; filed or cut with difficulty; crystals large and small mixed; sometimes runs thick; contraction in cooling a maximum.

Bright Gray. Toughness and hardness most suitable for working; ultimate cohesion and elastic range generally are balanced most advantageously; crystals uniform, very minute.

Dull Gray. Less tough than the preceding; other characters alike; contraction in cooling a minimum.

Dark Gray. Most fusible; remains long fluid; exudes graphite in cooling; soils the fingers; crystals large and lamellar; ultimate cohesion a minimum, and elastic range a maximum.

211. The gray iron is most suitable where strength is required; and the white, where hardness is the principal requisite.

212. The color and lustre, presented by the surface of a recent fracture, are the best indications of the quality of iron. A uniform dark gray color, and high metallic lustre, are indications of the best and strongest. With the same color, but less lustre, the iron will be found to be softer and weaker, and to crumble readily. Iron without lustre, of a dark and mottled color, is the softest and weakest of the gray varieties.

Iron of a light gray color and high metallic lustre, is usually very hard and tenacious. As the color approaches to white, and the metallic lustre changes to vitreous, hardness and brittleness become more marked, until the extremes of a dull, or grayish white color, and a very high vitreous lustre, are attained, which are the indications of the hardest and most brittle of the white variety.

213. The quality of cast iron may also be tested, by striking a smart stroke with a hammer on the edge of a casting. If the blow produces a slight indentation, without any appearance of

fracture, it shows that the iron is slightly malleable, and, therefore, of a good quality; if, on the contrary, the edge is broken, it indicates brittleness in the material, and a consequent want of strength.

214. The strength of cast iron varies with its density; and this element depends upon the temperature of the metal when drawn from the furnace; the rate of cooling; the head of metal under which the casting is made; and the bulk of the casting.

215. The density of iron cast in vertical moulds increases, according to Mr. Mallet's experiments, very rapidly from the top downward, to a depth of about four feet below the top; from this point to the bottom, the rate of increase is very nearly uniform. All other circumstances remaining the same, the density decreases with the bulk of the casting; hence large are proportionally weaker than small castings.

216. From all of these causes, by which the strength of iron may be influenced, it is very difficult to judge of the quality of a casting by its external characters; in general, however, if the exterior presents a uniform appearance, devoid of marked inequalities of surface, it will be an indication of uniform strength.

217. The economy in the manufacture of cast iron, arising from the use of the hot blast, has naturally directed attention to the comparative merits between iron produced by this process and that from the cold blast. This subject has been ably investigated by Messrs. Fairbairn and Hodgkinson, and their results published in the *Seventh Report of the British Association.*

Mr. Hodgkinson remarks on this subject, in reference to the results of his experiments: "It is rendered exceedingly probable that the introduction of a heated blast into the manufacture of cast iron, has injured the softer irons, while it has frequently mollified and improved those of a harder nature; and considering the small deterioration that" some "irons have sustained, and the apparent benefit to those of" others, "together with the great saving effected by the heated blast, there seems good reason for the process becoming as general as it has done."

218. From a number of specific gravities given in these Reports, the mean specific gravity of cold blast iron is nearly 7.091, that of hot blast 7.021.

219. Mr. Fairbairn concludes his Report with these observations, as the results of the investigations of himself and Mr. Hodgkinson: "The ultimatum of our inquiries, made in this way, stands, therefore, in the ratio of strength, 1000 for the cold blast to 1024.8 for the hot blast; leaving the small fractional difference of 24.8 in favor of the hot blast."

"The relative powers to sustain impact, are likewise in favo of the hot blast, being in the ratio of 1000 to 1226.3"

220. *Wrought Iron.* The color, lustre, and texture of a recent fracture, present, also, the most certain indications of the quality of wrought iron. The fracture submitted to examination, should be of bars at least one inch square; or, if of flat bars, they should be at least half an inch thick; otherwise, the texture will be so greatly changed, arising from the greater elongation of the fibres, in bars of smaller dimensions, as to present none of those distinctive differences observable in the fracture of large bars.

221. The surface of a recent fracture of good iron, presents a clear gray color, and high metallic lustre; the texture is granular, and the grains have an elongated shape, and are pointed and slightly crooked at their ends, giving the idea of a powerful force having been employed to produce the fracture. When a bar, presenting these appearances, is hammered, or drawn out into small bars, the surface of fracture of these bars will have a very marked fibrous appearance, the filaments being of a white color and very elongated.

222. When the texture is either laminated, or crystalline, it is an indication of some defect in the metal, arising either from the mixture of foreign ingredients, or else from some neglect in the process of forging.

223. *Burnt iron* is of a clear gray color, with a slight shade of blue, and of a slaty texture. It is soft and brittle.

224. *Cold short iron*, or iron that cannot be hammered when cold without breaking, presents nearly the same appearance as burnt iron, but its color inclines to white. It is very hard and brittle.

225. *Hot short iron*, or that which breaks under the hammer when heated, is of a dark color without lustre. This defect is usually indicated in the bar by numerous cracks on the edges.

226. The fibrous texture, which is developed only in small bars by hammering, is an inherent quality of good iron; those varieties which are not susceptible of receiving this peculiar texture, are of an inferior quality, and should never be used for purposes requiring great strength: the filaments of bad varieties are short, and the fracture is of a deep color, between lead gray and dark gray.

227. The best wrought iron presents two varieties; the *Hard* and *Soft*. The hard variety is very strong and ductile. It preserves its granular texture a long time under the action of the hammer, and only developes the fibrous texture when beaten, or drawn out into small rods: its filaments then present a silver white appearance.

228. The soft variety is weaker than the hard; it yields easily to the hammer; and it commences to exhibit, under its action

e fiorous texture in tolerably large bars. The color ι the ›res is between a silver white and lead gray.

229. Iron may be naturally of a good quality, and stil, from being badly refined, not present the appearances which are regarded as sure indications of its excellence. Among the defects arising from this cause are *blisters*, *flaws*, and *cinder-holes*. Generally, however, if the surface of fracture presents a texture partly crystalline and partly fibrous, or a fine granular texture, in which some of the grains seem pointed and crooked at the points, together with a light gray color without lustre, it will indicate natural good qualities, which require only careful refining to be fully developed.

230. The strength of wrought iron is very variable, as it depends not only on the natural qualities of the metal, but also upon the care bestowed in forging, and the greater or less compression of its fibres, when drawn or hammered into bars of different sizes.

231. In the Report made by the sub-committee, Messrs. John son and Reeves, on the strength of Boiler Iron, (*Journal of Franklin Institute*, vol. 20, *New Series*,) it is stated that the following order of superiority obtains among the different kinds of pig metal, with respect to the malleable iron which they furnish:—1 *Lively gray*; 2 *White*; 3 *Mottled gray*; 4 *Dead gray*; 5 *Mixed metals*.

The Report states, "So far as these experiments may be considered decisive of the question, they favor the lighter complexion of the cast metal, in preference to the darker and mottled varieties; and they place the mixture of different sorts among the worst modifications of the material to be used, where the object is mere tenacity."

232. These experiments also show that piling iron of different degrees of fineness in the same plate is injurious to its quality, owing to the consequent inequality of the welding.

233. From these experiments, the mean specific gravity of boiler iron is 7.7344, and of bar iron 7.7254.

234. *Durability of Iron.* The durability of iron, under the different circumstances of exposure to which it may be submitted, depends on the manner in which the casting may have been made; the bulk of the piece employed; the more or less homogéneousness of the mass; its density and hardness.

235. Among the most recent and able researches upon the action of the ordinary corrosive agents on iron, and the preservative means to be employed against them, those of Mr. Mallet, given in the Report already mentioned, hold the first rank. A brief recapitulation of the most prominent conclusions at which he has arrived, is all that can be attempted in this place.

236. When iron is only partly immersed in water, or wholly immersed in water composed of strata of different densities, like that of tidal rivers, a voltaic pile of one solid and two fluid bodies is formed, which causes a more rapid corrosion than when the liquid is of uniform density.

237. The corrosive action of the foul sea water of docks and harbors is far more powerful than that of clear sea, or fresh water, owing to the action of the hydro-sulphuric acid which, being disengaged from the mud, impregnates the water, and acts on the iron.

238. In clear fresh river water, the corrosive action is less than under any other circumstances of immersion; owing to the absence of corrosive agents, and the firm adherence of the oxide formed, which presents a hard coat that is not washed off as in sea water.

239. In clear sea water, the rate of corrosion of iron bars, one inch thick, is from 3 to 4 tenths of an inch for cast iron in a century, and about 6 tenths of an inch for wrought iron.

240. Wrought iron corrodes more rapidly in hot sea water than under any other circumstances of immersion.

241. The same iron when chill cast corrodes more rapidly than when cast in green sand; this arises from the chilled surface being less uniform, and therefore forming voltaic couples of iron of different densities, by which the rapidity of corrosion is increased.

242. Castings made in dry sand and loam are more durable under water than those made in green sand.

243. Thin bars of iron corrode more rapidly than those of more bulk. This difference in the rate of corrosion is more striking in the soft, or *graphitic* specimens of cast iron, than in the hard and silvery. It is caused by the more rapid rate of cooling in thin than in thick bars, by which the density of the surface of the former becomes less uniform. These causes of destructibility may, in some degree, be obviated in castings composed of ribbed pieces, by making the ribs of equal thickness with the main pieces, and causing them to be cooled in the sand, before stripping the moulds.

244. The hard crust of cast iron promotes its durability; when this is removed to the depth of one fourth of an inch, the iron corrodes more rapidly in both air and water.

245. Corrosion takes place the less rapidly in any variety of iron, in proportion as it is more homogeneous, denser, harder, and closer grained, and the less graphitic.

246. The more ordinary means used to protect iron against the action of corrosive agents, consist of paints and varnishes. These, under the usual circumstances of atmospheric exposure

are of but slight efficacy, and require to be frequently renewed. In water, they are all rapidly destroyed, with the exception of boiled coal-tar, which, when laid on hot iron, leaves a bright and solid varnish of considerable durability and protective power.

247. The rapidly increasing purposes to which iron has been applied, within the last few years, has led to researches upon the agency of *electro-chemical* action, as a means of protecting it from corrosion, both in air and water. Among the processes resorted to for this purpose, that of *zincking*, or as it is more commonly known, *galvanizing* iron has been most generally introduced. The experiments of Mr. Mallet, on this process, are decidedly against zinc as a permanent electro-chemical protector. Mr. Mallet states, as the result of his observations, that zinc applied in fusion, in the ordinary manner, over the whole surface of iron, will not preserve it longer than about two years; and that, so soon as oxidation commences at any point of the iron, the protective power of the zinc becomes considerably diminished, or even entirely null. Mr. Mallet concludes, "On the whole, it may be affirmed that, under all circumstances, zinc has not yet been so applied to iron, as to rank as an electro-chemical protector towards it in the strict sense; hitherto it has not become a preventive, but merely a more or less effective palliative to destruction."

248. In extending his researches on this subject, with alloys of copper and zinc, and copper and tin, Mr. Mallet found that the alloys of the last metals accelerate the corrosion of iron, when voltaically associated with it in sea water; and that an alloy of the two first, represented by $23Zn + 8Cu$, in contact with iron, protects it as fully as zinc alone, and suffers but little loss from the electro-chemical action; thus presenting a protective energy more permanent and invariable than that of zinc, and giving a nearer approximation to the solution of the problem, "to obtain a mode of electro-chemical protection such, that while the iron shall be preserved the protector shall not be acted on, and whose protection shall be invariable."

249. In the course of his experiments, Mr. Mallet ascertained that the softest gray cast iron bears such a voltaic relation to hard bright cast iron, when immersed in sea water and voltaically associated with it, that although oxidation will not be prevented on either, it will still be greatly retarded on the hard, at the expense of the soft iron.

250. In concluding the details of his important researches on this subject, Mr. Mallet makes the following judicious remarks: "The engineer of observant habit will soon have perceived, that in exposed works in iron, equality of section or scantling, in all parts sustaining equal strain, is far from ensuring equal passive power of permanent resistance, unless, in addition to a general

allowance for loss of substance by corrosion, this latter element be so provided for, that it shall be equally balanced over the whole structure; or, if not, shall be compelled to confine itself to portions of the general structure, which may lose substance without injuring its stability."

"The principles we have already established sufficiently guide us in the modes of effecting this; regard must not only be had to the contact of dissimilar metals, or of the same in dissimilar fluids, but to the scantling of the casting and of its parts, and to the contact of cast iron with wrought iron or steel, or of one sort of cast iron with another. Thus, in a suspension bridge, if the links of the chains be hammered, and the pins rolled, the latter, where equally exposed, will be eaten away long before the former. In marine steam-boilers, the rivets are hardened by hammering until cold; the plates, therefore, are corroded through round the rivets before these have suffered sensibly; and in the air-pumps and condensers of engines working with sea water, or in pit work, and pumps lifting mineralized or 'bad' water from mines, the cast iron perishes first round the holes through which wrought-iron bolts, &c., are inserted. And abundant other instances might be given, showing that the effects here spoken of are in practical operation to an extent that should press the means of counteracting them on the attention of the engineer."

251. Since Mr. Mallet's Report to the British Association, he has invented two processes for the protection of iron from the action of the atmosphere and of water; the one by means of a coating formed of a triple alloy of zinc, mercury, and sodium, or potassium; the other by an amalgam of palladium and mercury.

252. The first process consists of forming an alloy of the metals used, in the following manner. To 1292 parts of zinc by weight, in a state of fusion, 202 parts of mercury are added, and the metals are well mixed, by stirring with a rod of dry wood, or one of iron coated with clay; sodium, or potassium is next added, in small quantities at a time, in the proportion of one pound to every ton by weight of the other two metals. The iron to be coated with this alloy is first cleared of all adhering oxide, by immersing it in a warm dilute solution of sulphuric, or of hydro-chloric acid, washing it in clear cold water, and detaching all scales, by striking it with a hammer; it is then scoured clean by the hand with sand, or emery, under a small stream of water, until a bright metallic lustre is obtained; while still wet, it is immersed in a bath formed of equal parts of the cold saturated solutions of chloride of zinc and sal-ammoniac, to which as much more solid sal-ammoniac is added as the solution will take up. The iron is allowed to remain in this bath until it is covered by minute bubbles of gas; it is then taken out, allowed to drain a few seconds, and plunged

into the fused alloy, from which it is withdrawn so soon as it has acquired the same temperature. When taken from the metallic bath, the iron should be plunged in cold water and well washed.

253. Care must be taken that the iron be not kept too long in the metallic bath, otherwise it may be fused, owing to the great affinity of the alloy for iron. At the proper fusing temperature of the alloy, about 680° Fahr., it will dissolve plates of iron one eighth of an inch thick in a few seconds; on this account, whenever small articles of iron have to be protected, the affinity of the alloy for iron should be satisfied, by fusing some iron in it before immersing that to be coated.

254. The other process, which has been termed *palladiumizing*, consists in coating the iron, prepared as in the first process for the reception of the metallic coat, with an amalgam of palladium and mercury.

COPPER.

255. The most ordinary and useful application of this metal in constructions, is that of sheet copper, which is used for roof coverings, and like purposes. Its durability under the ordinary changes of atmosphere is very great. Sheet copper, when quite thin, is apt to be defective, from cracks arising from the process of drawing it out. These may be remedied, when sheet copper is to be used for a water-tight sheathing, by tinning the sheets on one side. Sheets prepared in this way have been found to be very durable.

The alloys of copper and zinc, known under the name of *brass*, and those of copper and tin, known as *bronze*, *gun-metal*, and *bell-metal*, are, in some cases, substituted for iron, owing to their superior hardness to copper, and being less readily oxidized than iron.

ZINC.

256. This metal is used mostly in the form of sheets; and for water-tight sheathings it has nearly displaced every other kind of sheet metal. The pure metallic surface of zinc soon becomes covered with a very thin, hard, transparent oxide, which is unchangeable both in air and water, and preserves the metal beneath it from farther oxidation. It is this property of the oxide of zinc, which renders this metal so valuable for sheathing purposes; but its durability is dependent upon its not being brought into contact with iron in the presence of moisture, as the galvanic action which would then ensue, would soon destroy the zinc. On the same account zinc should be perfectly free from the presence of iron as a very small quantity of the oxide of this last metal when contained in zinc, is found to occasion its rapid destruction.

257. Besides the alloys of zinc already mentioned, this metal alloyed with copper forms one of the most useful *solders*; and its alloy with lead has been proposed as a *cramping metal* for uniting the parts of iron work together, or iron work to other materials, in the place of lead, which is usually employed for this purpose, but which accelerates the destruction of iron in contact with it.

TIN.

258. The most useful application of tin is as a coating for sheet iron, or sheet copper: the alloy which it forms, in this way, upon the surfaces of the metals in question, preserves them for some time from oxidation. Alloyed with lead it forms one of the most useful solders.

LEAD.

259. Lead in sheets forms a very good and durable roof covering, but it is inferior to both copper and zinc in tenacity and durability; and is very apt to tear asunder on inclined surfaces, particularly if covered with other materials, as in the case of the capping of water-tight arches.

PAINTS AND VARNISHES.

260. *Paints* are mixtures of certain fixed and volatile oils, chiefly those of linseed and turpentine, with several of the metallic salts and oxides, and other substances which are used either as pigments, or to give what is termed a *body* to the paint, and also to improve its drying properties.

261. Paints are mainly used as protective agents to secure wood and metals from the destructive action of air and water. This they but imperfectly effect, owing to the unstable nature of the oils that enter into their composition, which are not only destroyed by the very agents against which they are used as protectors, but by the chemical changes which result from the action of the elements of the oil upon the metallic salts and oxides.

262. Paints are more durable in air than in water. In the latter element, whether fresh or salt, particularly if foul, paints are soon destroyed by the chemical changes which take place, both from the action of the water upon the oils, and that of the hydrosulphuric acid contained in foul water upon the metallic salts and oxides.

263. However carefully made or applied, paints soon become permeable to water, owing to the very minute pores which arise from the chemical changes in their constituents. These changes will have but little influence upon the preservative action of paints upon wood exposed to the effects of the atmosphere, provided the wood be well seasoned before the paint is applied, and that the

latter be renewed at suitable intervals of time. On metals these changes have a very important bearing. The permeability of the paint to moisture causes the surface of the metal under it to rust, and this cause of destruction is, in most cases, promoted by the chemical changes which the paint undergoes.

264. *Varnishes* are solutions of various resinous substances in solvents which possess the property of drying rapidly. They are used for the same purposes as paints, and have generally the same defects.

265. The following are some of the more usual compositions of paints and varnishes.

White Paint, (for exposed wood.)

White lead, ground in oil	80
Boiled oil	9
Raw oil	9
Spirits turpentine	4

The white lead to be ground in the oil, and the spirits of turpentine added.

Black Paint.

Lamp-black	28
Litharge	1
Japan varnish	1
Linseed oil, boiled	73
Spirits turpentine	1

Lead Color.

White lead, ground in oil	75
Lamp-black	1
Boiled linseed oil	23
Litharge	0.5
Japan varnish	0.5
Spirits turpentine	2.5

Gray, or Stone Color, (for buildings.)

White lead ground in oil	78
Boiled oil	9.5
Raw oil	9.5
Spirits of turpentine	3
Turkey umber	0.5
Lamp-black	0.25

Lackers for Cast Iron.

1	—Black lead, pulverized	12
	Red lead	12
	Litharge	5
	Lamp-black	5
	Linseed oil	66

2.—Anti-corrosion	40 lbs.
	Grant's black, ground in oil	4 "
	Red lead, as a dryer	3 "
	Linseed oil	4 gals.
	Spirits turpentine	1 pint.

Copal Varnish.

Gum copal, (in clean lumps)	26.5
Boiled linseed oil	42.5
Spirits turpentine	31

Japan Varnish.

Litharge	4
Boiled oil	87
Spirits turpentine	2
Red lead	6
Umber	1
Gum shellac	8
Sugar of lead	2
White vitriol	1

The proportions of the above compositions are given in 100 parts, by weight, with the exception of lacker 2.

The beautiful black polish on the Berlin castings for ornamental purposes, is said to be produced by laying the following composition on the hot iron, and then baking it.

Bitumen of India	0.5
Resin	0.5
Drying oil	1.0
Copal, or amber varnish	1.0

Enough oil of turpentine is to be added to this mixture to make it spread.

266. From experiments made by Mr. Mallet, on the preservative properties of paints and varnishes for iron immersed in water, it appears that caoutchouc varnish is the best for iron in hot water, and asphaltum varnish under all other circumstances; but that boiled coal-tar, laid on hot iron, forms a superior coating to either of the foregoing.

267. Mr. Mallet recommends the following compositions for a paint, termed by him *zoofagous* paint, and a varnish to be used to preserve zincked iron both from corrosion and from fouling in sea water.

Varnish for zincked Iron.

To 50 lbs. of foreign asphaltum, melted and boiled in an iron vessel for three or four hours, add 16 lbs. of red lead and litharge ground to a fine powder, in equal proportions, with 10 gals. of

drying linseed oil, and bring the whole to a nearly boiling temperature. Melt, in a second vessel, 8 lbs. of gum-animé; to which add 2 gals. of drying linseed oil at a boiling heat, with 12 lbs. of caoutchouc partially dissolved in coal-tar naphtha. Pour the contents of the second vessel into the first, and boil the whole gently, until the varnish, when taken up between two spatulas, is found to be tough and ropy. This composition, when quite cold, is to be thinned down for use with from 30 to 35 gals. of spirits of turpentine, or of coal naphtha.

268. It is recommended that the iron should be heated before receiving this varnish, and that it should be applied with a spatula, or a flexible slip of horn, instead of the ordinary brush.

When dry and hard, it is stated that this varnish is not acted upon by any moderately diluted acid, or alkali; and, by long immersion in water, it does not form a partially soluble hydrate, as is the case with purely resinous varnishes and oil paints. It can with difficulty be removed by a sharp-pointed tool; and is so elastic, that a plate of iron covered with it may be bent several times before it will become detached.

Zoofagous Paint.

269. To 100 lbs. of a mixture of drying linseed oil, red lead, sulphate of barytes, and a little spirits of turpentine, add 20 lbs. of the oxychloride of copper, and 3 lbs. of yellow soap and common rosin, in equal proportions, with a little water.

When zincked iron is exposed to the atmosphere alone, the varnish is a sufficient protection for it; but when it is immersed in sea water, and it is desirable, as in iron ships, to prevent it from fouling, by marine plants and animals attaching themselves to it, the paint should be used, on account of its poisonous qualities. The paint is applied over the varnish, and is allowed to harden three or four days before immersion.

RESULTS OF EXPERIMENTAL RESEARCHES ON THE STRENGTH OF MATERIALS.

270. Whatever may be the physical structure of materials, whether fibrous or granular, experiment has shown that they all possess certain general properties, among the most important of which to the engineer are those of *contraction*, *elongation*, *deflection*, *torsion*, and *lateral adhesion*, and the resistances which these offer to the forces by which they are called into action.*

* *See Note D., Appendix.*

271 All solid bodies, when submitted to strains by which any of these properties are developed, have, within certain limits, termed the *limits of elasticity*, the property of wholly or partially resuming their original state, when the strain is taken off. This property is usually denominated the *elastic force*, and has for its measure, in the case of contraction, or elongation, the ratio between the force which causes the one or the other of these states and the fraction which measures the degree of contraction, or elongation.

272. To what extent bodies possess the property of total recovery of form, when relieved from a strain, is still a matter of doubt. It has been generally assumed, that the elasticity of a material does not undergo permanent injury by any strain less than about one third of that which would entirely destroy its force of cohesion, thereby causing rupture. But from the most recent experiments on this point made by Mr. Hodgkinson on cast iron, it appears that the restoring power of this material is destroyed by very slight strains; and it is rendered probable that this and most other materials receive a permanent change of form, or *set*, under any strain, however small.

273. The extension, or contraction of a solid, may be effected either by a force acting in the direction in which the contraction, or elongation takes place, or by one acting transversely, so as to bend the body. Experiments have been made to ascertain, directly, the proportion between the amount of contraction, or elongation, and the forces by which they are produced. From these experiments, it results, that the contractions, or elongations are, within certain limits, proportional to the forces, but that an equal amount of contraction, or elongation, is not produced by the same amount of force. From the experiments of Mr. Hodgkinson and M. Duleau, it appears, that in cast and malleable iron the contraction, or elongation, caused by the same amount of pressure, or tension, is nearly equal; while in timber, according to Mr. Hodgkinson, the amount of contraction is about four fifths of the elongation for the same force.

274. When a solid of any of the materials used in constructions is acted upon by a force so as to produce deflection, experiment has shown that the fibres towards the concave side of the bent solid are contracted, while those towards the convex side are elongated; and that, between the fibres which are contracted and those which are elongated, others are found which have not undergone any change of length. The part of the solid occupied by these last fibres has received the name of the *neutral line*, or *neutral axis*.

275. The hypothesis usually adopted, with respect to the circumstances attending this kind of strain, is that the contractions

and elongations of the fibres on each side of the neutral axis are proportional to their distances from this line; and that, for slight deflections, the neutral axis passes through the centre of gravity of the sectional area. From experiments, however, by Mr. Hodgkinson and Mr. Barlow, it appears that the neutral axis, in forged iron and cast iron, lies nearer to the concave than to the convex surface of the bent solid, and, probably, shifts its position when the degree of deflection is so great as to cause rupture. In timber, according to Mr. Barlow, the neutral axis lies nearest to the convex surface; and, from his experiments on solids of forged iron and timber with a rectangular sectional figure, he places the neutral axis at about three eighths of the depth of the section from the convex side in timber, and between one third and one fifth of the depth of the section from the concave side in forged iron.

276. When the strain to which a solid is subjected is sufficiently great to destroy the cohesion between its particles, and cause rupture, experiment has shown that the force producing this effect, whether it act by tension, so as to draw the fibres asunder, or by compression, to crush them, is proportional to the sectional area of the solid. The measure, therefore, of the resistance offered by a solid to rupture, in either of these cases, is that force which will rupture a sectional area of the solid represented by unity.

277. From experiments made to ascertain the circumstances of rupture by a tensile force, it appears that the solid torn apart exhibits a surface of fracture more or less even, according to the nature of the material.

278. Most of the experiments on the resistance to rupture by compression, have been made on small cubical blocks, and have given a measure of this resistance greater than can be depended upon in practical applications, when the height of the solid exceeds three times the radius of its base. This point has been very fully elucidated in the experiments of Mr. Hodgkinson upon the rupture by compression of solids with circular and rectangular bases. These experiments go to prove, that the circumstances of rupture, and the resistance offered by the solid, vary in a constant manner with its height, the base remaining the same. In columns of cast iron, with circular sectional areas, it was found that the resistance remained constant for a height less than three times the radius of the base; that, from this height to one equal to six times the radius of the base, the resistance still remained constant, but was less than in the former case; and that, for any height greater than six times the radius of the base, the resistance decreased with the height. In the two first cases the solids were found to yield either by the upper portion sliding off upon the lower, in the direction of a plane making a constan

angle with the axis of the solid; or else by separating into conical, or wedge-shaped blocks, having the upper and lower surfaces of the solid as their bases, the angle at the apex being double that made by the plane and axis of the solid. With regard to the resistances, it was found that they varied in the ratio of the area of the bases of the solids. Where the height of the solid was greater than six times the radius of the base, rupture generally took place by bending.

279. From experiments by Mr. Hodgkinson, on wood and other substances, it would appear that like circumstances accompany the rupture of all materials by compression; that is, within certain limits, they all yield by an oblique surface of fracture, the angle of which with the axis of the solid is constant for the same material; and that the resistances offered within these limits are proportional to the areas of the bases.

280. Among the most interesting deductions drawn by Mr. Hodgkinson, from the wide range of his experiments upon the strength of materials, is the one which points to the existence of a constant relation between the resistances offered by materials of the same kind to rupture from compression, tension, and a transverse strain. The following *Table* gives these relations, assuming the measure of the crushing force at 1000.

DESCRIPTION OF MATERIAL.	Crushing force per square inch.	Mean tensile force per square inch.	Mean transverse force of a bar 1 inch square and 1 foot long.
Timber	1000	1900	85.1
Cast iron	1000	158	19.8
Stone	1000	100	9.8
Glass, (plate and crown)	1000	123	10

281. STRENGTH OF STONE. The marked difference in the structure, and in the proportions of the component elements frequently observed in stone from the same quarry, would lead to the conclusion that corresponding variations would be found in the strength of stones belonging to the same class; a conclusion which experiment has confirmed. The experiments made by different individuals on this subject, from not having been conducted in the same manner, and from the omission in most cases of details respecting the structure and component elements of the material tried, have, in some instances, led to contradictory results. A few facts, however, of a general character have been ascertained, which may serve as guides in ordinary cases; but in important structures, where heavy pressures are to be sustained, direct experiment is the only safe course for the engineer to follow, in selecting a material from untried quarries.

282. Owing to the ease with which stones generally break under a percussive force, and from the comparatively slight resistance they offer to a tensile force, and to a transverse strain, they are seldom submitted in structures to any other strain than one of compression; and cases but rarely occur where this strain is not greatly beneath that which the better class of building stones can sustain permanently, without undergoing any change in their physical properties. Where the durability of the stone, therefore, is well ascertained, it may be safely used without a resort to any specific experiment upon its strength, whenever, in its structure and general appearance, it resembles a material of the same class known to be good.

283. The following Table exhibits the principal results of experiments made by Mr. G. Rennie, and published in the *Philosophical Transactions of* 1818. The stones tried were in small cubes, measuring one and a half inches on the edge. The table gives the pressure, in tons, borne by each superficial inch of the stone at the moment of crushing.

DESCRIPTION OF STONE.	Spec. gravity.	Crushing w'ght.
Granites.		
Aberdeen, (*blue*)	2.625	4.83
Peterhead	–	3.70
Cornwall	2.662	2.83
Sand-stones.		
Dundee	2.530	2.96
Do.	2.506	2.70
Derby, (*red and friable*)	2.316	1.40
Lime-stones.		
Marble, (*white-veined Italian*)	2.726	4.32
Do. (*white Brabant*)	2.697	4.11
Limerick, (*black compact*)	2.598	3.95
Devonshire, (*red marble*)		3.31
Portland stone, (*fine-grained oolite*) . .	2.428	2.04

The following results are taken from a series of experiments made under the direction of Messrs. Bramah & Sons, and published in *Vol.* 1, *Transactions of the Institution of Civil Engineers*. The first column of numbers gives the weights, in tons, borne by each superficial inch when the stones commenced to fracture; the second column gives the crushing weight, in tons, on the same surface.

DESCRIPTION OF STONE.	Aver. weight producing fractures.	Average crushing weight.
Granites.		
Herme	4.77	6.64
Aberdeen, (*blue*)	4.13	4.64
Heytor	3.94	6.19
Dartmoor	3.52	5.48
Peterhead, (*red*)	2.88	4.88
Peterhead, (*blue gray*)	2.86	4.36
Sand-stones.		
Yorkshire	2.87	3.94
Craigleith	1.89	2.97
Humbie	1.69	2.06
Whitby	1.00	1.06

The following Table is taken from one published in *Vol. 2, Civil Engineer and Architect's Journal,* which forms a part of the Report on the subject of selecting stone for the New Houses of Parliament. The specimens submitted to experiment were cubical blocks measuring two inches on an edge.

DESCRIPTION OF STONE.	Specific gravity.	Weight producing fracture.	Crushing w'ght.
Sand-stones.			
Craigleith	2.232	1.89	3.5
Darley Dale	2.628	2.75	3.1
Heddon	2.229	0.82	1.75
Kenton	2.247	1.51	2.21
Mansfield	2.338	0.88	1.64
Magnesian Lime-stones.			
Bolsover	2.316	2.21	3.75
Huddlestone	2.147	1.03	1.92
Roach Abbey	2.134	0.75	1.73
Park Nook	2.138	0.32	1.92
Oolites.			
Ancaster	2.182	0.75	1.04
Bath Box	1.839	0.56	0.66
Portland	2.145	0.95	1.75
Ketton	2.045	0.69	1.18
Lime-stones.			
Barnack	2.090	0.50	0.79
Chilmark, (*silicious*)	2.481	1.32	2.19
Hamhill	2.260	0.69	1.80

The numbers of the first column give the specific gravities

those in the second column the weight in tons on a square inch, when the stone commenced to fracture; and those in the third the crushing weight on a square inch.

The following Table exhibits the results of experiments on the resistance of stone to a *transverse strain*, made by Colonel Pasley, on prisms 4 inches long, the cross section being a square of 2 inches on a side; the distance between the points of support 3 inches.

DESCRIPTION OF STONE.	Weight of stone per cubic foot in lbs.	Average breaking weight in lbs.
1. Kentish Rag	165.69	4581
2. Yorkshire Landing . . .	147.67	2887
3. Cornish granite . . .	172.24	2808
4. Portland	148.08	2682
5. Craigleith	144.47	1896
6. Bath	122.58	666
7. Well-burned bricks	91.71	752
8. Inferior bricks	–	329

284. The conductors of the experiments on the stone for the New Houses of Parliament, Messrs. Daniell and Wheatstone, who also made a chemical analysis of the stones, and applied to them Brard's process for testing their resistance to frost, have appended the following conclusions from their experiments:— "If the stones be divided into classes, according to their chemical composition, it will be found that in all stones of the same class there exists generally a close relation between their various physical qualities. Thus it will be observed that the specimen which has the greatest specific gravity possesses the greatest cohesive strength, absorbs the least quantity of water, and disintegrates the least by the process which imitates the effects of weather. A comparison of all the experiments shows this to be the general rule, though it is liable to individual exceptions."

"But this will not enable us to compare stones of different classes together. The sand-stones absorb the least quantity of water, but they disintegrate more than the magnesian lime-stones, which, considering their compactness, absorb a great deal."

285. Rondelet, from a numerous series of experiments on the same subject, published in his work, *Art de Bâtir*, has arrived at like conclusions with regard to the relations between the specific gravity and strength of stones belonging to the same class.

286. Among the results of the more recent experiments on this subject, those obtained by Mr. Hodgkinson, showing the relation

between the crushing, the tensile, and the transverse strength of stone, have already been given.

M. Vicat, in a memoir on the same subject, published in the *Annales des Ponts et Chaussées*, 1833, has arrived at an opposite conclusion from Mr. Hodgkinson, stating, as the results of his experiments, that no constant relation exists between the crushing and tensile strength of stone in general, and that there is no other means of determining these two forces, but by direct experiment in each case.

287. The influence of form on the strength of stone, and the circumstances attending the rupture of hard and soft stones, have been made the subject of particular experiments by Rondelet and Vicat. Their experiments agree in establishing the points that the crushing weight is in proportion to the area of the base. Vicat states, more generally, that the permanent weights borne by similar solids of stone, under like circumstances, will be as the squares of their homologous sides. These two authors agree on the point that the circular form of the base is the most favorable to strength. They differ on most other points, and particularly on the manner in which the different kinds of stone yield by rupture.

288. *Practical Deductions.* Were stones placed under the same circumstances in structures as in the experiments made to ascertain their strength, there would be no difficulty in assigning what fractional part of the weight which, in the comparatively short period usually given to an experiment, will crush them, could be borne by them permanently with safety. But, independently of the accidental causes of destruction to which structures are exposed, imperfections in the material itself, as well as careless workmanship, from which it is often placed in the most unfavorable circumstances of resistance, require to be guarded against. M Vicat, in the memoir before-mentioned. states that a permanent strain of $\frac{30}{100}$ of the crushing force of experiment, may be borne by stone without danger of impairing its cohesive strength, provided it be placed under the most favorable circumstances of resistance. This fraction of the crushing weight of experiment is greater than ordinary circumstances would justify, and it is recommended in practice not to submit any stone to a greater permanent strain than one tenth of the crushing weight of experiments made on small cubes measuring about two inches on an edge.

The following Table shows the permanent strain, and crushing weight, for a square foot of the stones in some of the most remarkable structures in Europe.

	Permanent strain.	Crushing weight.
Pillars of the dome of St. Peter's, (*Rome*) . .	33330	536000
Do. St. Paul's, (*London*) . .	39450	537000
Do. St. Geneviève, (*Paris*) .	60000	456000
Do. Church of Toussaint, (*Angers*) . .	90000	900000
Lower courses of the piers of the Bridge of Neuilly	3600	570000

The stone employed in all the structures enumerated in the Table, is some variety of lime-stone.

289. *Expansion of Stone from Heat.* Experiments have been made in this country by Prof. Bartlett, and in England by Mr. Adie, to ascertain the expansion of stone for every degree of Fahrenheit. The experiments of Prof. Bartlett give the following results:

Granite expands for every degree . .	.000004825
Marble " "	.000005668
Sand-stone " "	.000009532

Table of the Expansion of Stone, &c., from the Experiments of Alexander J. Adie, Civil Engineer, Edinburgh.

DESCRIPTION OF STONE.	Decimal of an inch on 23 inches for 180° F.	Decimal of length for 180° F.	Decimal of length for 1° F.	Remarks.
1. Roman cement . . .	.0330043	.0014349	.00000750	
2. Sicilian white marble .	.0325392	.0014147	.00000780	One experiment, (*moist.*)
	.0253946	.00110411	.00000613	Mean of three, (*dry.*)
3. Carrara marble . .	.0274344	.0011928	.00000662	One experiment, (*moist.*)
	.0150405	.0006539	.00000363	Mean of two, (*dry.*)
4. Sand-stone, (*Craigleith*)	.0270093	.0011743	.00000652	Mean of four experiments.
5. Slate, (*Welch*) . . .	.0238659	.0010376	.00000576	Mean of three do.
6. Red granite, (*Peterhead*)	.0220416	.0009583	.00000532	One experiment, (*moist.*)
	.0206266	.0008968	.00000498	Mean of two, (*dry.*)
7. Arbroath pavement .	.0206652	.0008985	.00000499	Mean of four experiments.
8. Caithness pavement .	.0205788	.0008947	.00000497	Mean of three do.
9. Green-stone, (*Ratho*) .	.0186043	.0008089	.00000449	Mean of three do
10. Gray granite, (*Aberdeen*)	.01815695	.00078943	.00000438	Mean of two do.
11. Best stock brick . .	.0126542	.0005502	.00000306	Mean of two do.
12. Fire brick	.0113334	.0004928	.00000274	Mean of two do.
13. Black marble, (*Galway*)	.0102394	.00044519	.00000247	Mean of three do.

290. Strength of Mortars. A very wide range of experiments has been made, within a few years back, by engineers both at home and abroad, upon the resistance offered by mortars to a transversal strain, with a view to compare their qualities, both as regards their constituent elements and the processes followed in their manipulation. As might naturally have been anticipated these experiments have presented very diversified, and, in many instances, contradictory results. The general conclusions, however, drawn from them, have been nearly the same in the majority

of cases, and they furnish the engineer with the most reliable guides in this important branch of his art.

83. The usual method of conducting these experiments has been to subject small rectangular prisms of mortar, resting on points of support at their extremities, to a transversal strain applied at the centre point between the bearings. This, perhaps, is as unexceptionable and convenient a method as can be followed for testing the comparative strength of mortars.

84. M. Vicat, in the work already cited, gives the following as the average resistances on the square inch offered by mortars to a force of traction, the deductions being drawn from experiments on the resistance to a transversal strain.

Mortars of very strong hydraulic lime	.	170 pounds.
" ordinary do.	.	140 "
" medium do.	.	100 "
" common lime	.	40 "
" do. (bad quality)	.	10 "

These experiments were made upon prisms a year old, which had been exposed to the ordinary changes of weather. With regard to the best hydraulic mortars of the same age which had been, during the same period, either immersed in water or buried in a damp position, M. Vicat states that their average strength may be estimated at [illegible] pounds on the square inch.

85. Colonel Totten, in his work on hydraulic and common mortars, has given in detail a large number of experiments on the transversal strength of [illegible] mortars made by subjecting small rectangular parallelopipeds of mortar six inches in length and two inches square, to a transversal strain applied at the centre point between the bearings, which were four inches apart. From these experiments he deduces the following general conclusions.

[illegible]

[illegible]

[illegible]

[illegible]

2d. That common mortar is the stronger and harder as the quantity of sand is less.

3d. That any addition of common lime to a mortar of hydraulic cement and sand weakens the mortar, but that a little lime may be added without any considerable diminution of the strength of the mortar, and with a saving of expense.

4th. The strength of common mortars is considerably improved by the addition of an artificial puzzolana, but more so by the addition of an hydraulic cement.

5th. Fine sand generally gives a stronger mortar than coarse sand.

6th. Lime slaked by sprinkling gave better results than lime slaked by drowning. A few experiments made on air-slaked lime were unfavorable to that mode of slaking.

7th. Both hydraulic and common mortar yielded better results when made with a small quantity of water than when made thin.

8th. Mortar made in the mortar-mill was found to be superior to that mixed in the usual way with a hoe.

9th. Fresh water gave better results than salt water.

295. STRENGTH OF CONCRETE AND BETON. From experiments made on concrete, prepared according to the most approved process in England, by Colonel Pasley, it appears that this material is very inferior in strength to good brick, and the weaker kinds of natural stones.

From experiments made by Colonel Totten on beton, the following conclusions are drawn:

That beton made of a mortar composed of hydraulic cement, common lime, and sand, or of a mortar of hydraulic cement and sand, without lime, was the stronger as the quantity of sand was the smaller. But there may be 0.50 of sand, and 0.25 of common lime, without sensible deterioration; and as much as 1.00 of sand, and 0.25 of lime, without great loss of strength.

Beton made with just sufficient mortar to fill the void spaces between the fragments of stone was found to be less strong than that made with double this bulk of mortar. But Colonel Totten remarks, that this result is perhaps attributable to the difficulty of causing so small a quantity of mortar to penetrate the voids, and unite all the fragments perfectly, in experiments made on a small scale.

The strongest beton was obtained by using quite small fragments of brick, and the weakest from small, rounded, stone gravel.

A beton formed by pouring grout among fragments of stone, or brick, was inferior in strength to that made in the usual way with mortar

Comparing the strength of the betons on which the experiments were made, which were eight months old when tried, with

that of a sample of sound red sand stone of good quality, it appears that the strongest prisms of beton were only half as strong as the sand-stone.

296. Strength of Timber. A wide range of experiments has been made on the resistance of timber to compression, extension, and a transverse strain, presenting very variable results. Among the most recent, and which command the greatest confidence from the ability of their authors, are those of Professor Barlow and Mr. Hodgkinson: the former on the resistance to extension and a transverse strain; the latter on that to compression.

297. *Resistance to Extension.* The following Table exhibits the specific gravity, and the mean resistance per square inch of various kinds of timber, from the experiments of Prof. Barlow.

DESCRIPTION OF TIMBER.	Spec. grav.	Mean strength of cohesion per square inch.
Ash, (*English*)	0.760	17000
Beech, do.	0.700	11500
Box	1.000	20000
Deal, (*Christiana*)	0.680	11000
Do. (*Memel*	0.590	11000
Elm	0.540	5780
Fir, (*New England*)	0.550	12000
Do. (*Riga*)	0.750	12600
Do. (*Mar Forest*)	0.700	12000
Larch, (*Scotch*)	0.540	7000
Locust	0.950	20580
Mahogany	0.637	8000
Norway spars	0.580	12000
Oak, (*English*) from	0.700	9000
to	0.900	15000
Do. (*African*)	0.980	14400
Do. (*Adriatic*)	0.990	14000
Do. (*Canadian*	0.872	12000
Do. (*Dantzic*)	0.760	14500
Pear	0.646	9800
Poon	0.600	14000
Pine, (*pitch*)	0.660	10500
Do. (*red*)	0.660	10000
Teak	0.750	15000

298. But few direct experiments have been made upon the elongations of timber from a strain in the direction of the fibres. From some made in France by MM. Minard and Desormes, it would appear that bars of oak having a sectional area of one square inch, will be elongated .001176 of their length by a strain of one ton.

299 *Resistance to Compression.* The following Table exhibits the results obtained by Mr. Hodgkinson from experiments on short cylinders of timber with flat ends. The diameter of each cylinder was one inch, and its height two inches. The results, in the first column, are a mean from about three experiments on timber moderately dry, being such as is used for making models for castings; those in the second column were obtained, in a like manner, from similar specimens, which were turned and kept dry in a warm place two months longer. A comparison of the results in the two columns, shows the effect of drying on the strength of timber; wet timber not having half the strength of the same when dry. The circumstances of rupture were the same as already stated in the general observations under this head; the height of the wedge which would slide off in timber being about half the diameter, or thickness of the specimen crushed.

DESCRIPTION OF WOOD.	Strength per square inch in lbs.	
Alder	6831	6960
Ash	8683	9363
Baywood	7518	7518
Beech	7733	19363
Birch, (*American*)	3297	11663
Do. (*English*)	3297	6402
Cedar	5674	5863
Crab	6499	7148
Red deal	5748	6586
White deal	6781	7293
Elder	7451	9973
Elm	–	10331
Fir, (*spruce*)	6499	6819
Hornbeam	4533	7289
Mahogany	8198	8198
Oak, (*Quebec*)	4231	5982
Do. (*English*)	6484	10058
Do. (*Dantzic, very dry*)	–	7731
Pine, (*pitch*)	6790	6790
Do. (*yellow, full of turpentine*)	5375	5445
Do. (*red*)	5395	7518
Poplar	3107	5124
Plum, (*wet*)	3654	–
Do. (*dry*)	8241	to 1049
Sycamore	7082	–
Teak	–	12101
Larch, (*fallen two months*)	3201	5568
Walnut	6063	7227
Willow	2898	6128

300. *Resistance of Square Pillars.* Mr. Hodgkinson has

made a number of invaluable experiments on the strength of pillars of timber, and of columns of iron and steel, and from them has deduced formulæ for calculating the pressure which they will support before breaking. The experiments on timber were made on pillars with flat ends. The following are the formulæ from which their strength may be estimated.

Calling the breaking weight in lbs. W.
" the side of the square base in inches d.
" the length of the pillar in feet l.

Then for long columns of oak, in which the side of the square base is less than $\frac{1}{30}$th the height of the column;

$$W = 24542 \frac{d^4}{l^2}.$$

and for red deal,

$$W = 17511 \frac{d^4}{l^2}.$$

For shorter pillars, where the ratio between their thickness and height is such that they still yield by bending, the strength is estimated by the following formula:

Calling the weight calculated from either of the preceding formulæ, W.

Calling the crushing weight, as estimated from the preceding Table, W'.

Calling the breaking weight in lbs., W''.

Then the formula for the strength is

$$W'' = \frac{WW'}{W + \frac{3}{4}W'}.$$

In each of the preceding formulæ d must be taken in inches, and l in feet.

301. *Resistance to Transverse Strains.* As timber, from the purposes to which it is applied, is for the most part exposed to a transverse strain, the far greater number of experiments have been made to ascertain the relations between the strain, the deflection caused by it, and the linear dimensions of the piece subjected to the strain. These relations have been made the subject of mathematical investigations, founded upon data derived from experiment, which will be given in the Appendix. The following Table exhibits the results of experiments made upon beams having a rectangular sectional area, which were laid horizontally upon supports at their ends, and subjected to a strain applied at the middle point between the supports, in a vertical direction.

For a more convenient application of the formulæ to the results of the experiments, the notation adopted in the preceding Art will be here given.

Call the transverse force necessary to break the beam in lbs., *W*
" the distance between the supports in inches, *l*.
" the horizontal breadth of the sectional area in inches, *b*.
" the vertical depth " " " *d*.
" the deflection arising from a weight *w* in inches, *f*.

Table of Experiments with the foregoing Notation.

DESCRIPTION OF WOOD.	Specific grav.	Values of *l*.	Values of *b*.	Value of *d*.	Value of *f*.	Value of *w*.	Value of *W*.	Authors of experiments.
		Inches.	Inches.	Inches.	Inches.	lbs.	lbs.	
Oak, (*English*) . . .	.934	84	2	2	1.280	200	637	Prof. Barlow.
Do. (*Canadian*) . .	.872	84	2	2	1.080	225	673	"
Pine, (*American*) . .	–	84	2	2	0.931	150	–	"
Oak, (*English*) . . .	–	30	1	1	0.5	137	–	Tredgold.
White spruce, (*Canadian*)	.465	24	1	1	0.5	180	285	"
White pine, (*American*) .	.455	85.2	2.75	5.55	0.177	777	5189	Lieut. Brown.
Black spruce, do. .	.490	85.2	2.75	5.55	0.177	892	5646	"
Southern pine, do. .	.872	85.2	2.75	5.54	0.177	1175	9237	"

302. *Resistance to Detrusion.* From the experiments of Prof. Barlow, it appears that the resistance offered by the lateral adhesion of the fibres of fir, to a force acting in a direction parallel to the fibres, may be estimated at 592 lbs. per square inch.

Mr. Tredgold gives the following as the results of experiments on the resistance offered by adhesion to a force applied perpendicularly to the fibres to tear them asunder.

Oak . .	2316 lbs. per square inch.	
Poplar . .	1782 "	"
Larch, 970 to	1700 "	"

303. STRENGTH OF CAST IRON. The most recent experiments on the strength of this material are those of Mr. Hodgkinson. Those, particularly, made by him on the subject of the strength of columns, and the most suitable form of cast-iron beams to sustain a transversal strain, have supplied the engineer and architect with the most valuable guide in adapting this material to the various purposes of structures.

304. *Resistance to Extension.* From a few experiments made by Mr. Rennie and Captain Brown, the tensile strength of cast iron varies from 7 to 9 tons per square inch.

The experiments of Mr. Hodgkinson upon both hot and cold blast iron give the tensile strength from 6 to 9¾ tons per square inch.

From some experiments made on American cast iron, under the direction of the Franklin Institute, the mean tensile strength is 20834 lbs., or 9⅓ tons per square inch.

305. *Resistance to Compression.* The general circumstances attending the rupture of this material by compression, drawn from

he experiments of Mr. Hodgkinson, have already been given The angle of the wedge resulting from the rupture is about 55°.

The mean crushing weight derived from experiments upon short cylinders of hot blast iron was 121,685 lbs., or 54 tons 6¼ cwt. per square inch.

That on short prisms of the same, with square bases, 100,738 lbs., or 44 tons 19¼ cwt. per square inch

That on short cylinders of cold blast iron was 125,403 lbs., or 55 tons 19½ cwt. per square inch.

That on short prisms of the same, having other regular figures for their bases, was 100,631 lbs., or 44 tons 18¼ cwt. per square inch.

Mr. Hodgkinson remarks with respect to the forms of base differing from the circle: "In the other forms the difference of strength is but little; and therefore we may perhaps admit that difference of form of section has no influence upon the power of a short prism to bear a crushing force."

In remarking on the circumstances attending the rupture, Mr. Hodgkinson farther observes: "We may assume, therefore, without assignable error, that in the crushing of short iron prisms of various forms, longer than the wedge, the angle of fracture will be the same. This simple assumption, if admitted, would prove at once, not only in this material, but in others which break in the same manner, the proportionality of the crushing force in different forms to the area; since the area of fracture would always be equal to the direct transverse area multiplied by a constant quantity dependent upon the material."

Table exhibiting the Ratio of the Tensile to the Compressive Forces in Cast Iron, from Mr. Hodgkinson's Experiments.

DESCRIPTION OF METAL.		Compressive force per square inch.	Tensile force per square inch.	Ratio.
Devon iron,	No. 3. Hot blast	145,435	21,907	6.638 : 1
Buffery iron,	No. 1. Hot blast	86,397	13,434	6.431 : 1
Do.	" Cold blast	93,385	17,466	5.346 : 1
Coed-Talen iron,	No. 2. Hot blast	82,734	16,676	4.961 : 1
Do.	" Cold blast	81,770	18,855	4.337 : 1
Carron iron,	No. 2. Hot blast	108,540	13,505	8.037 : 1
Do.	" Cold blast	106,375	16,683	6.376 : 1
Carron iron,	No. 3. Hot blast	133,440	17,755	7.515 : 1
Do.	" Cold blast	115,442	14,200	8.129 : 1

306. *Resistance of Cylindrical Columns.* The experiments under this head were made upon solid and hollow columns, both ends of which were either flat or rounded, fixed or loose, or one

end flat and the other rounded. In the case of columns with rounded ends, the pressure was applied in the direction of the axis of the column.

The following extracts are made from Mr. Hodgkinson's paper on this subject, published in the *Report of the British Association* of 1840.

"1st. In all long pillars of the same dimensions, the resistance to crushing by flexure is about three times greater when the ends of the pillars are flat, than when they are rounded.

"2d. The strength of a pillar, with one end rounded and the other flat, is the arithmetical mean between that of a pillar of the same dimensions with both ends round, and one with both ends flat. Thus, of three cylindrical pillars, all of the same length and diameter, the first having both its ends rounded, the second with one end rounded and one flat, and the third with both ends flat, the strengths are as 1, 2, 3, nearly.

"3d. A long, uniform, cast-iron pillar, with its ends firmly fixed, whether by means of discs or otherwise, has the same power to resist breaking as a pillar of the same diameter, and half the length, with the ends rounded or turned so that the force would pass through the axis.

"4th. The experiments show that some additional strength is given to a pillar by enlarging its diameter in the middle part; this increase does not, however, appear to be more than one seventh, or one eighth of the breaking weight.

"5th. The index of the power of the diameter to which the strength of long pillars with rounded ends is proportional, is 3.76 nearly, and 3.55 in those with flat ends, as appeared from the results of a great number of experiments; or the strength of both may be taken as the 3.6 power of the diameter nearly.

"6th. In pillars of the same thickness, the strength is inversely proportional to the 1.7 power of the length nearly.

"Thus the strength of a solid pillar with rounded ends, the diameter of which is d, and the length l, is as $\frac{d^{3.6}}{l^{1.7}}$."

"The absolute strength of solid pillars, as appeared from the experiments, are nearly as below.

In pillars with rounded ends,

$$\text{Strength in tons} = 14.9\,\frac{d^{3.6}}{l^{1.7}}.$$

In pillars with flat ends,

$$\text{Strength in tons} = 44.16\,\frac{d^{3.6}}{l^{1.7}}.$$

In hollow pillars nearly the same laws were found to obtain thus, if D and d be the external and internal diameters of a pillar

whose length is l, the strength of a hollow cylinder of which the ends were moveable (as in the connecting rod of a steam-engine) would be expressed by the formula below.

$$\text{Strength in tons} = 13\,\frac{D^{3.6} - d^{3.6}}{l^{1.7}}.$$

In hollow pillars, whose ends are flat, we had from experiment as before,

$$\text{Strength in tons} = 44.3\,\frac{D^{3.6} - d^{3.6}}{l^{1.7}}$$

The formulæ above apply to all pillars whose length is not less than about thirty times the external diameter; for pillars shorter than this, it is necessary to have recourse to the 'formula,' given under the head of Strength of Timber, for short pillars of timber, substituting for W and W' in that formula, the proper values applicable to cast iron."

307. *Similar Pillars.* "In similar pillars, or those whose length is to the diameter in a constant proportion, the strength is nearly as the square of the diameter, or of any other linear dimension; or, in other words, the strength is nearly as the area of the transverse section."

"In hollow pillars, of greater diameter at one end than the other, or in the middle than at the ends, it was not found that any additional strength was obtained over that of cylindrical pillars."

"The strength of a pillar, in the form of the connecting rod of a steam-engine," (that is, the transverse section presenting the figure of a cross +,) "was found to be very small, perhaps not half the strength that the same metal would have given if cast in the form of a uniform hollow cylinder."

"A pillar irregularly fixed, so that the pressure would be in the direction of the diagonal, is reduced to one third of its strength. Pillars fixed at one end and moveable at the other, as in those flat at one end and rounded at the other, break at one third the length from the moveable end; therefore, to economize the metal, they should be rendered stronger there than in other parts."

308. *Long-continued Pressure on Pillars.* "To determine the effect of a load lying constantly on a pillar, Mr. Fairbairn had, at the writer's suggestion, four pillars cast, all of the same length and diameter. The first was loaded with 4 cwt., the second with 7 cwt., the third with 10 cwt., and the fourth with 13 cwt.; this last load was $\frac{97}{100}$ of what had previously broken a pillar of the same dimensions, when the weight was carefully laid on without loss of time. The pillar loaded with 13 cwt. bore the weight between five and six months, and then broke."

309. *General Properties of Pillars.* "In pillars of wrought

iron, steel, and timber, the same laws, with respect to rounded and flat ends, were found to obtain, as had been shown to exist in cast iron."

"Of rectangular pillars of timber, it was proved experimental y that the pillar of greatest strength of the same material is a square."

310. *Comparative Strengths of Cast Iron, Wrought Iron, Steel, and Timber.*

"It resulted from the experiments upon pillars of the same dimensions but of different materials, that if we call the strength of cast iron 1000, we shall have for wrought iron 1745, cast stee. 2518, Dantzic oak 108.8, red deal 78.5."

311. *Resistance to Transverse Strains.* The following Tables and deductions are drawn from the experiments of Messrs. Hodgkinson and Fairbairn, on hot and cold blast iron, as published in their *Reports to the British Association in* 1837.

Table exhibiting the results of experiments by Mr. Hodgkinson on bars of hot blast iron 5 feet long, with a rectangular sectional area; the bars resting horizontally on props 4 feet 6 inches apart; the weight being applied at the middle of the bar.

EXPERIMENT 1. Rectangular bar, 1.00 inch broad, 1.00 " deep. Weight of bar, 15 lbs. 2 oz.			EXPERIMENT 13. Rectangular bar, 1.03 inches broad, 3.00 " deep.			EXPERIMENT 14. Rectangular bar, 1.02 inches broad, 4.98 " deep. Weight 78 lbs.		
Weight in lbs.	Deflection in inches.	Set, or deflection when unloaded.	Weight in lbs.	Deflection in inches.	Set in inches.	Weight in lbs.	Deflection in inches.	Set in inches.
16	.037	visible	1474	–	.001	5867	.127	–
23	.052	increased	1605	.130	.003	6798	.153	.01
30	.079	.001 !	1866	.156	.006	7730	.177	–
56	.132	.002	2126	.185	.010	8661	.207	–
112	.271	.008	2388	.212	.012	9593	.235	–
224	.588	.037	2649	.243	.017	10524	.275	.03
336	.940	.087	2910	.272	.022	11387	broke	–
448	1.360	.181	3172	.307	.030	–	–	–
469	broke	–	3433	.340	.038	–	–	–
–	–	–	3694	.378	.050	–	–	–
–	–	–	3956	broke	–	–	–	–
Ultimate deflection 1.444 inches.			Ultimate deflection .416 inch.			Ultimate deflection .299 inch.		

Results of experiments, by the same, on the transverse strength of cold blast iron; length of bars, and distance between the points of support the same as in the preceding Table.

Experiment 1 Rectangular bar, 1.025 inch deep, 1.002 " broad. Weight, 15 lbs. 6 oz.			Experiment 12. Rectangular bar, 3.00 inches deep, 1.02 " broad. Weight, 46 lbs. 8 oz.			Experiment 13. Rectangular bar, 4.98 inches deep, 1.03 " broad Weight, 78 lbs.		
Weight in lbs.	Deflection in inches.	Set in inches.	Weight in lbs.	Deflection in inches.	Set in inches.	Weight in lbs.	Deflection in inches.	Set in inches.
16	.033	visible	1082	.091	.003	4936	.110	.013
30	.062	increased	1343	.111	.006	5867	.130	–
56	.120	.002	1605	.138	.008	6798	.153	.020
112	.240	.007	1866	.164	.010	7730	.179	.025
168	.370	.014	2126	.190	.012	8662	.195	–
224	.510	.028	2388	.220	.015	9593	.219	.034
280	.649	.041	2649	.250	.019	10525	.250	.042
336	.798	.061	2910	.281	.026	10588	broke	–
392	.953	.084	3172	.310	.031	–	–	–
448	1.120	.120	3433	.345	.037	–	–	–
504	1.310	.170	3694	.378	.046	–	–	–
514	it bore	–	3825	broke	–	–	–	–
518	broke	–	–	–	–	–	–	–
Ultimate deflection 1.36 inch.			Ultimate deflection 0.395 inch.			Ultimate deflection 0.252.		

312. The following remarks are extracted from the same Report: "I had remarked, in some of the experiments, that the elasticity of the bars was injured much earlier than is generally conceived; and that instead of its remaining perfect till one third, or upwards, of the breaking weight was laid on, as is generally admitted by writers, it was evident that $\frac{1}{7}$th, or less, produced in some cases a considerable set or defect of elasticity; and judging from its slow increase afterwards, I was persuaded that it had not come on by a sudden change, but had existed, though in a less degree, from a very early period."

"From what has been stated above, deduced from experiments made with great care, it is evident that the maxim of loading bodies within the elastic limit, has no foundation in nature; but it will be considered as a compensating fact, that materials will bear for an indefinite period a much greater load than has hitherto been conceived."

313. "We may admit," from the mean results, "that the strength of rectangular bars is as the square of the depth."

314. *Effects of time upon the deflections caused by a permanent load on the middle of horizontal bars.*

The following Table exhibits the results of Mr. Fairbairn's experiments on this point. The experiments were made on bars 5 feet long, 1.05 inch deep; the one of cold blast iron, 1.03 inch broad; the other of hot blast, 1.01 broad; distance between the points of support 4 feet 6 inches. The constant weight suspended at the centre of the bars was 280 lbs. This weight remained on from March 11th, 1837, to June 23d, 1838.

Cold blast iron. Deflection in inches.	Date of observation.	Temp.	Hot blast iron. Deflection in inches.	Ratio of increase of deflections.
.930	March 11th, 1837,	–	1.064	—
.963	June 23d, 1838,	78°	1.107	—
.033	Increase,	–	.043	1000 : 1303

315. Mr. Fairbairn in his Report remarks on the above and like results: "The hot blast bar in these experiments being more deflected than the cold blast, indicates that the particles are more extended and compressed in the former iron, with the same weight, than in the latter. This excess of deflection may in some degree account for the rapidity of increase, which it will be observed is considerably greater in the hot than in the cold blast bar."

"It appears from the present state of the bars, (which indicate a slow but progressive increase in the deflections,) that we must at some period arrive at a point beyond their bearing powers; or otherwise to that position which indicates a correct adjustment of the particles in equilibrium with the load. Which of the two points we have in this instance attained is difficult to determine: sufficient data, however, are adduced to show that the weights are considerably beyond the elastic limit, and that cast iron will support loads to an extent beyond what has usually been considered safe, or beyond that point where a permanent set takes place."

316. *Effects of Temperature.* Mr. Fairbairn remarks: "The infusion of heat into a metallic substance may render it more ductile, and probably less rigid in its nature; and I apprehend it will be found weaker, and less secure under the effects of heavy strain. This is observable to a considerable extent in the experiments" on transverse strength "ranging from 26° up to 190° Fahr."

'The cold blast at 26° and 190°, is in strength as 874 : 743,

The hot blast at 26° and 190°, is in strength as 811 : 731,

being a diminution in strength as 100 : 85 for the cold blast, and 100 to 90 for the hot blast, or 15 per cent. loss of strength in the cold blast, and 10 per cent. in the hot blast."

"A number of the experiments made on No. 3 iron have given

extraordinary and not unfrequently unexpected results. Generally speaking, it is an iron of an irregular character, and presents less uniformity in its texture than either the first or second qualities; in other respects it is more retentive, and is often used for giving strength and tenacity to the finer metals."

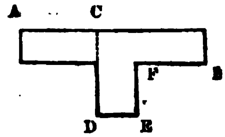
"At 212° we have in the No. 3 a much greater weight sustained than what is indicated by the No. 2 at 190°; and at 600° there appears in both hot and cold blast the anomaly of increased strength as the temperature is advanced from boiling water to melted lead, arising from the greater strength of the No. 3 iron.'

317. *Influence of Form in Cast Iron upon the Transverse Strength of Beams.* Upon no point, respecting the strength of cast iron, have the experiments of Mr. Hodgkinson led to more valuable results to the engineer and architect, than upon the one under this head. The following Tables give the results of experiments on bars of a uniform cross section, (thus T,) cast from hot and cold blast iron. The bars were 7 feet long, and placed, for breaking, on supports 6 feet 6 inches asunder.

Table exhibiting the results of experiments on bars of hot blast iron of the form of cross section as above.

Experiment 4. Bar broken T as shown with the rib downward.			Experiment 5. Bar broken ⊥ as shown with the rib upward.		
Weight in lbs.	Deflection in inches.	Set.	Weight in lbs.	Deflection in inches.	Set.
7	.015	visible	7	–	not visible
14	.032	.001	14	.025	visible
21	.046	.002	21	.045	.002
28	.064	.004	28	.065	.003
56	.130	.005	56	.134	.005
112	.273	.020	112	.270	.015
168	.444	.035	224	.580	.058
224	.618	.058	336	.895	.101
280	.813	.093	448	1.224	.155
336	1.030	.130	560	1.585	.235
364	broke	–	672	1.985	.330
–	–	–	784	2.410	.490
–	–	–	896	3.450	.722
–	–	–	1008	4.140	1.040
–	–	–	1064	–	–
–	–	–	1120	broke	–
Ultimate deflection 1.126 inches.			Fracture caused by a wedge 2.98 inches long and 1.05 deep, of this form  flying out. Ultimate deflection 4.890		

Note. The annexed diagram shows the form of the uniform cross section of the bars. The linear dimensions of the cross section in the two experiments were as follows:



Length of parallelogram	AB	5 inches	Expt. 4.	5 inches	Expt. 5.
Depth "	AB	0.30 "		0.30 "	
Total depth of bar .	CD	1.55 "		1.56 "	
Breadth of rib . . .	DE	0.36 "		0.365 "	

Table exhibiting results of experiments on bars of cold blast iron 5 feet long, of the same form of cross section as in preceding Table.

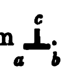
Experiment 4. Bar broken with rib downward.			Experiment 5. Bar broken with rib upward.		
Weight in lbs.	Deflection in inches.	Set.	Weight in lbs.	Deflection in inches.	Set.
112	.03	–	112	.03	–
224	.07	–	224	.07	–
336	.11	–	336	.11	–
392	.13	.005	448	.15	–
420	.14	.007	560	.19	.005
448	.15	.010	616	.21	.010
560	.19	.012	672	.23	–
672	.23	.015	728	–	.015
784	.28	.023	784	.27	–
896	.33	.030	896	.31	–
958	.35	–	1008	.35	–
980	broke	–	1120	.39	–
–	–	–	1344	.48	–
–	–	–	1568	.57	–
–	–	–	1792	.67	–
–	–	–	2016	.80	–
–	–	–	2240	.95	–
–	–	–	2296	it bore	–
–	–	–	2352	broke	–
Ultimate deflection .36.			Ultimate deflection 1.03. Fracture by a wedge breaking out as in Experiment 5, Hot Blast.		

Note. The linear dimensions of the cross section of the bars in the above Table, were nearly the same as those in the prece

ding Table, with the exception of the total depth CD, which in these last two experiments, was 2.27 inches, or a little more.

318. The object had in view by Mr. Hodgkinson, in the experiments recorded in the two preceding Tables, was twofold; the one to ascertain the circumstances under which a permanent set, or injury to elasticity takes place; the other to ascertain the effect of the form of cross section on the transverse strength of cast iron. The following extracts from the Report, give the principal deductions of Mr. Hodgkinson on these points.

"In experiments 4 and 5," (on hot blast iron,) "which were on longer bars than the others, cast for this purpose, and for another mentioned further on, the elasticity (in Expt. 4) was sensibly injured with 7 lbs., and in the latter (Expt. 5) with 14 lbs., the breaking weights being 364 lbs., and 1120 lbs. In the former of these cases a set was visible with $\frac{1}{52}$, and in the other with $\frac{1}{80}$ of the breaking weight, showing that there is no weight, however small, that will not injure the elasticity."

"When a body is subjected to a transverse strain, some of its particles are extended and others compressed; I was desirous to ascertain whether the above defect in elasticity arose from tension or compression, or both. Experiments 4 and 5 show this; in these a section of the casting, which was uniform throughout, had the form . During the experiments the broad part *ab* was laid horizontally upon supports; the vertical rib *c* in the latter experiment being upward, in the former downward. When it was downward the rib was extended, when upward the rib was compressed. In both cases the part *ab* was the fulcrum; it was thin, and therefore easily flexible; but its breadth was such that it was nearly inextensible and incompressible, comparatively, with the vertical rib. We may therefore assume, that nearly the whole flexure which takes place in a bar of this form, arises from the extension or compression of the rib, according as it is downward or upward. In Expt. 4 we have extension nearly without compression, and in Expt. 5 compression almost without extension. These experiments were made with great care. They show that there is but little difference in the quantity of set, whether it arises from tension or compression."

"The set from compression, however, is usually less than that from extension, as is seen in the commencement of the two experiments, and near the time of fracture in that submitted to tension. The deflections from equal weights are nearly the same whether the rib be extended or compressed, but the ultimate strengths, as appears from above, are widely different."

319. *Form of Cast Iron Beam best adapted to resist a Trans-*

verse Strain. The experiments of Mr. Hodgkinson on this subject, published in the *Memoirs of the Literary and Philosophical Society of Manchester, Second Series,* vol. 5, are of equal interest with those just detailed, both in their general results and practical bearing. From these experiments, the conclusion drawn is that the form of beam in the annexed diagrams is the most favorable for resistance to transverse strains.

Fig. *a*.

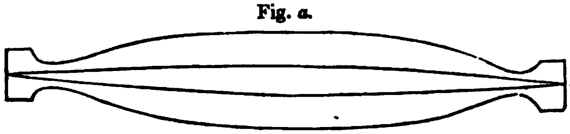


Fig. *b*.

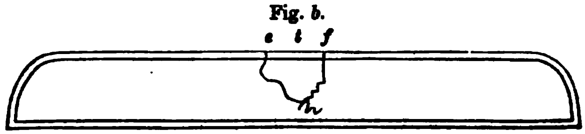


Fig. *c*.

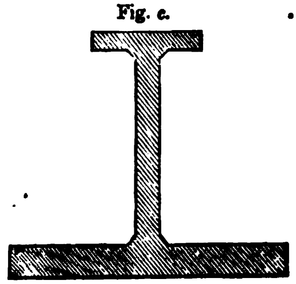


Fig. *a* represents the plan, Fig. *b* the elevation, and Fig. *c* the cross section (enlarged) at the middle of the beam. From the Figs. it will be seen, that the beam consists of three parts; a bottom flanch of uniform depth, but variable breadth, tapering from the centre towards the extremities, where the points of support would be placed, so as to form a portion of the common parabola on each side of the axis of the beam, the vertex of each parabola being at the centre of the beam. The object of this form of flanch was to make it, according to theory, the strongest, with the same amount of material, to bear a weight uniformly distributed over it. The top flanch is of a like form, but of much smaller breadth and depth than the bottom one. The two are united by a vertical rib of uniform depth and breadth.

The following are the relative dimensions of this form of beam which, from experiment, gave the most favorable result.

Distance of supports	**4 ft. 6 inches.**
Total depth of beam	**0 " $5\frac{1}{8}$ "**
Breadth of top flanch at centre of beam	**2.33 "**
" bottom flanch "	**6.66 "**
Uniform depth of top flanch	**0.31 "**
" bottom flanch	**0.66 "**
Thickness of vertical rib	**0.266 "**
Total area of cross section	**6.4 square inch**
Weight of beam	**71 lbs**

"This beam broke in the middle by compression with 26084 lbs., or 11 tons 13 cwt., a wedge separating from its upper side."

"The weights were laid gradually and slowly on, and the beam had borne within a little of its breaking weight a considerable time, perhaps half an hour."

"The form of the fracture and wedge is represented in the Fig. *b*, where *enf* is the wedge, *ef* = 5.1 inches, *tn* = 3.9 inches, angle *enf* = 82°."

"It is extremely probable, from this fracture, that the neutral point was at *n*, the vertex of the wedge, and therefore at $\frac{3}{4}$ths the depth of the beam, since $3.9 = \frac{3}{4} \times 5\frac{1}{8}$ nearly."

The relative dimensions above given were arrived at by "constantly making small additions" to the bottom flanch, until a point was reached where resistance to compression could no longer be sustained. The beams of this form, in all previous experiments, having yielded by the bottom flanch tearing asunder.

"The great strength of this form of cross section is an indisputable refutation of that theory which would make the top and bottom ribs of a cast iron beam equal."

"The form of cross section" (as above) "is the best which we have arrived at for the beam to bear an ultimate strain. If we adopt the form of beam, (as above,) I think we may confidently expect to obtain the same strength with a saving of upwards of $\frac{1}{4}$th of the metal."

320. *Rules for determining the ultimate Strength of Cast Iron Beams of the above forms.* From the results of his experiments, Mr. Hodgkinson has deduced the following very simple formulæ, for determining the breaking weight, in tons, when applied at the middle of a beam.

Call the breaking weight in tons, W.

Call the area of the cross section of the bottom flanch, taken at the middle of the beam, a.

Call the depth of the beam at the middle point, d.

Call the distance between the supports, l.

Then

$$W = 26\frac{ad}{l},$$

when the beam has been cast with the bottom flanch upward and

$$W = 24\frac{ad}{l}$$

when the beam has been cast on its side.

321. *Effect of Horizontal Impact upon cast iron bars, and*

Measure of the Resistance offered by cast iron to this force. The following Tables of experiments on this subject, and the results drawn from them, are taken from a paper by Mr. Hodgkinson, published in the *Fifth Report of the British Association.*

The bars under experiment were impinged upon by a weight suspended freely in such a position, that hanging vertically it was in contact with the side of the bar. The blow was given by allowing the weight to swing through different arcs. The bars were so confined against lateral supports, that they could take nc vertical motion.

Table of experiments on a cast iron bar, 4 *ft.* 6 *in. long,* 1 *in. broad,* ½ *in. thick, weighing* 7¼ *lbs., placed with the broadside against lateral supports* 4 *ft. asunder, and impinged upon by cast iron and lead balls weighing* 8½ *lbs., swinging through arcs of the radius* 12 *feet.*

Impact with leaden ball.			Impact with iron ball.		
Chord of arc fallen through in feet.	Observed chord of recoil of ball in inches.	Observed deflection of bar in inches.	Chord of arc fallen through in feet.	Observed chord of recoil of ball in inches.	Observed deflection of bar in inches.
1	6.5	.24	1	6.5	.23
2	13	.46	2	14	.46
3	19	.73	3	20	.65
4	27	.97	4	29	.98
5	34	1.30	5	37	1.32
6	47	1.60	6	48	1.65

"Before the experiments on impact were made upon this bar, it was laid on two horizontal supports 4 feet asunder, and weights gently laid on the middle bent it (in the same direction that it was afterwards bent by impact) as below:

28 lbs. bent it .37 inch.
56 lbs " .77 " Elasticity a little injured."

Table of experiments on a cast iron bar 7 ft. long, 1.08 in. broad and 1.05 in. thick, weighing 23¼ lbs., placed, as in preceding experiments, against supports 6 ft. 6 in. asunder, and bent by impacts in the middle. Impinging ball of cast iron weighing 20¾ lbs. Radius of arcs 16 feet.

Impact upon bar.		Impact upon the weight.	
Chord of arc fallen through.	Observed deflection in inches.	Chord of arc fallen through.	Observed deflection in inches.
2	.46	2	.31
3	.62	3	.43
4	.87	4	.69
5	1.03	5	.81
6	1.24	6	1.04
7	1.44	7	1.28
8	1.80	8	1.41
–	–	9	1.63

The results in the 3d and 4th columns of the above table were derived from allowing the ball to impinge against a weight of 56 lbs., hung so as to be in contact with the bar.

"Before the experiments on impact, the beam was laid on two supports 6 ft. 6 in. asunder, and was bent .78 in. by 123 lbs., (including the pressure from its own weight,) applied gently in the middle."

Tables of experiments on two cast iron bars, 4 ft. 6 in. long, full inch square, weighing 14 lbs. 10 oz. nearly, placed against supports 4 feet apart, and impinged upon by a cast iron ball weighing 44 lbs. Radius 16 ft.

Impact in the middle.		Impact at one fourth the length from the middle of the bars.		
Chords of arcs in feet.	Mean deflections of the two bars in inches.	Chords of arcs in feet.	Mean deflections of the two bars in inches.	Mean ratio of the deflections in the two cases.
2	.35	2	.24	–
3	.55	3	.42	–
4	.77	4	.52	694
5	.95	5	.64	–
5.5	1.05	5.5	.70	–
6	Broke in the middle	6	Broke at the point of impact	–

The results in the 1st of the above Tables are from bars struck

in the middle, those in the 2d Table are from bars struck at the middle point between the centre and extremity of the bar.

322. From the above and other experiments the conclusion is drawn, "that a uniform beam will bear the same blow, whether struck in the middle or half way between that and one end."

"From all the experiments it appears, that the deflection is nearly as the chord of the arc fallen through, or as the velocity of impact."

The following conclusions are drawn from the experiments.

(1.) "If different bodies of equal weight, but differing considerably in hardness and elastic force, be made to strike horizontally against the middle of a heavy beam supported at its ends, all the bodies will recoil with velocities equal to one another."

(2.) "If, as before, a beam supported at its ends be struck horizontally by bodies of the same weight, but different hardness and elastic force, the deflection of the beam will be the same whichever body be used."

(3.) "The quantity of recoil in a body, after striking against a beam as above, is nearly equal to (though somewhat below) what would arise from the full varying pressure of a perfectly elastic beam, as it recovered its form after deflection."

Note. This last conclusion is drawn from a comparison of the results of experiment with those obtained from calculation, in which the beam is assumed as perfectly elastic.

(4.) "The effect of bodies of different natures striking against a hard, flexible beam, seems to be independent of the elasticities of the bodies, and may be calculated, with trifling error, on a supposition that they are inelastic."

(5.) "The power of a uniform beam to resist a blow given horizontally, is the same in whatever part it is struck."

323. From the results of the experiments of Messrs. Fairbairn and Hodgkinson, on the properties of cold and hot blast iron, it appears that the ratio of their resistances to impact is 1000 to 1226.3, the resistance of cold blast being represented by 1000; the resistance, or power of the beam to bear a horizontal impact, being measured by the product of its breaking weight from a transverse strain at the middle of the beam and its ultimate deflection. This measure, Mr. Hodgkinson remarks, "supposes that all cast iron bars of the same dimensions, in our experiments, are of the same weight, and that the deflection of a beam up to the breaking weight, would be as the pressure. Neither of these is true; they are only approximations; but the difference in the weights of cast iron bars of equal size is very little, and taking them as the same, it may be inferred from my paper on Impact upon Beams, (*Fifth Report of the British Association,*) that the assumption above gives results near enough for practice."

324 Strength of Wrought Iron. This material, from its very extensive applications in structures where a considerable tensile force is to be resisted, as in suspension bridges, iron ties, &c., has been the subject of a very great number of experiments. Among the many may be cited those of Telford and Brown in England, Duleau in France, and the able and extensive series upon plate iron for steam boilers, made under the direction of the Franklin Institute, and published in the 19th and 20th vols. (*New Series*) of the *Journal of the Institute.*

Resistance to Extension. The following Tables exhibit the tensile strength of this material under ordinary temperatures, and in the different states in which it is used for structures.

Table exhibiting the Strength of Square and Round bars of Wrought Iron.

DESCRIPTION OF IRON.	Length of pieces in feet.	Extension before rupture in inches.	Breaking weight in tons.	Tensile strength per square inch.	Author.
Bar 1 inch square, *Welsh* .	1	22.75	29	29	Telford.
" " *Swedish* .	1	0.375	29	29	"
Round bar, 2 in. diam. " .	1	2.2	100	29.98	"
Bar, 1.31 inch square " .	3.5	0.19	40.95	23.75	Brown.
" 1.19 " " .	3.5	3.00	33.50	23.75	"
Round bar, 1.31 in. diam., *Russian*	3.5	2.25	36.10	26.50	"
Bar, 1.25 inch square, *Welsh* .	3.5	2.00	38.05	24.35	"
Round bar, 2 in. diam. " .	12.5	18.50	82.75	26.33	"
Bars reduced in the middle by hammering to 0.375 in. square	-	-	-	31.35	Brunel.
" " 0.50 "	-	-	-	30.80	"
Bar, *Missouri* . .	-	-	-	21.38	Franklin Institute.
" (slit rods)		-	-	22.32	"
" *Tennessee* . .	-	-	-	23.25	"
" *Salisbury, Connecticut*	-	-	-	25.89	"
" *Swedish* . .	-	-	-	25.97	"
" *Centre Co., Penn.* .	-	-	-	26.07	"
" *Lancaster Co., Penn.* .	-	-	-	26.18	"
" (cable iron) *English*	-	-	-	26.62	"
" do. hammer hardened "	-	-	-	31.70	"
" *Russian*	-	-	-	33.95	"
Wire, 0.323 in. diam. *Phillipsburg*	-	-	-	37.58	"
" 0.190 " "	-	-	-	32.98	"
" 0.156 " "	-	-	-	39.80	"
" 0.10 " *English*	-	-	-	35.81	Telford.

Table exhibiting the Mean Strength of Boiler Iron, per square inch in lbs., cut from plates with shears.

Process of manufacture.	Rough edge bar.	Edges filed uniformly.	Notches filed into bar on each edge.
Piled iron	53,045	56,081	63,266
Hammered plate . .	47,506	55,584	58,447
Puddled iron . . .	52,341	51,039	62,420

It is remarked in the Report of the Sub-committee, "that the inherent irregularities of the metal, even in the best specimens,

ai ether of rolled or hammered iron, seldom fall short of 10 or 15 per cent. of the mean strength."

From the same series of experiments, it appears that th strength of rolled plate lengthwise is about 6 per cent. greater than its strength crosswise.

In the *Tenth Report of the British Association* in 1840, Mr. Fairbairn has given the results of experiments on plate iron by Mr. Hodgkinson, from which it appears that the mean strength of iron plates lengthwise is 22.52 tons.

Crosswise	"	23.04 "
Single-riveted plates	"	18,590 lbs.
Double-riveted plates	"	22,258 "

Representing the strength of the plate by 100.

The double-riveted plates will be . .	70
The single " " . .	56.

325. Professor Barlow, in his *Report to the Directors of the London and Birmingham Railroad,* (Journal of Franklin Institute, July, 1835,) states, as the results of his experiments, that a bar of malleable iron one inch square is elongated the $\frac{1}{10,000}$th part of its length by a strain of one ton; that good iron is elongated the $\frac{1}{1000}$th part by a strain of 10 tons, and is injured by this strain, while indifferent, or bad iron is injured by a strain of 8 tons.

From the Report made to the Franklin Institute, it appears that the first set, or permanent elongation may take place under very different strains, varying with the character of the material. The most ductile iron yields permanently to a low degree of strain. The extremes by which a permanent set is given vary between the 0.416 and 0.872 of the ultimate strength; the mean of thirteen comparisons being 0.641.

326. *Resistance to Compression.* But few experiments have been published on the resistance of this material to compression. Rondelet states that it commences to yield under a pressure of about 70,800 lbs. per square inch, and that when the altitude of the specimen tried is greater than three times the diameter of the base it yields by bending. Mr. Hodgkinson states that the circumstances of its rupture from crushing indicate a law similar to what obtains in cast iron.

327. *Resistance to a Transverse Strain.* The following Tables exhibit the circumstances of deflection from a transverse strain on bars laid on horizontal supports; the weight being applied at the middle of the bar.

The Table I. gives the results on bars 2 inches square, laid on supports 33 inches asunder; Table II. the results on bars 2 inches deep, 1.9 in. broad, bearing as in Table I.

TABLE I. TABLE II.

Weight in tons.	Deflections in inches for each half ton.	Weight in tons.	Deflections in inches for each half ton
.75	.020	.250	–
1.00	.020	.50	.016
1.50	.020	1.00	.022
2.00	.030	1.50	.020
2.50	.020	2.00	.026
3.00	Set	2.25	.018
–	–	2.50	.026
–	–	2.75	.038
–	–	3.00	.092

The above experiments were made by Professor Barlow, and published in his Report already cited. He remarks on the results in Table II., that the elasticity was injured by 2.50 tons and destroyed by 3.00 tons.

328. Trials were made to ascertain mechanically the position of the neutral axis on the cross section. Professor Barlow remarks on these trials, that "the measurements obtained in these experiments being tension 1.6, compression 0.4, giving exactly the ratio of 1 to 4 in rectangular bars. These results seem the most positive of any hitherto obtained; still there can be little doubt this ratio varies in iron of different qualities; but looking to the preceding experiments, it is probably always from 1 to 3, to 1 to 5."

329. *Effects of time on the elongation of Wrought Iron from a constant strain of extension.* M. Vicat has given, in the *Annales de Chimie et de Physique*, vol. 54, some experiments on this point, made on iron wires which had not been annealed, by subjecting four wires, respectively, to strains amounting to the $\frac{1}{4}$, the $\frac{1}{3}$, the $\frac{1}{2}$, and $\frac{3}{4}$ of their tensile strength, during a period of 33 months.

From the results of these experiments it appears, that each wire, immediately upon the application of the strain to which it was subjected, received a certain amount of extension.

The first wire, which was subjected to a strain of $\frac{1}{4}$th its tensile strength, was found at the end of the time in question not to have acquired any increase of extension.

The second, submitted to $\frac{1}{3}$d its tensile strength, was elongated 0.027 in. per foot, independently of the elongation it at first received.

The third, subjected under like circumstances to a strain of $\frac{1}{2}$th its tensile strength, was elongated 0.40 in. per foot, besides its first elongation.

The fourtn, similarly subjected to ¾ths the tensile st.ength, was elongated 0.061, besides its first elongation.

From observations made during the experiments, it was found that, reckoning from the time when the first elongations took place, the rapidity of the subsequent elongations was nearly proportional to the times; and that the elongations from strains greater than ¼th the tensile strength are, after equal times, nearly proportiona to the strains.

330. M. Vicat remarks ir substance upon the results of these experiments, that iron wire, when not annealed, commenees to exhibit a permanent set when subjected to a strain between the ¼ and ⅓ of its tensile strength, and that therefore it is rendered probable that the wire ropes of a suspension bridge, which should be subjected to a like strain, would, when the vibratory motion to which such structures are liable is considered, yield constantly from year to year, until they entirely gave way.

M. Vicat farther remarks, in substance, that the measure of the resistance offered by materials to strains exerted only some minutes, or hours, is entirely relative to the duration of the experiments. To ascertain the absolute measure of this resistance, which should serve as a guide to the engineer, the materials ought to be subjected for some months to strains; while observations should be made during this period, with accurate instruments, upon the manner in which they yield under these strains.

331. *Effects of Temperature on the Tensile Strength of Wrought Iron* The experiments made under the direction of the Franklin Institute, already noticed, have developed some very curious facts of an anomalous character, with respect to the effect of an increase of temperature upon the strength of wrought iron. It was found that at high degrees of heat the tensile strength was greater up to a certain point than was exhibited by the same iron at ordinary temperatures. The Sub-committee in their Report remark: "This circumstance was noted at 212°, 392°, and 572°, rising by steps of 180° each from 32°, at which last point some trials have been made in melting ice. At the highest of these points, however, it was perceived that some specimens of the metal exhibited but little, if any, superiority of strength over that which they had possessed when cold, while others allowed of being heated nearly to the boiling point of mercury, before they manifested any decided indications of a weakening effect from increase of temperature."

"It hence became apparent that any law, taking for a basis the strength of iron in its ordinary condition, and at common temperatures, must be liable to great uncertainty, in regard to its application to different specimens of the metal. It was evident that the anomaly above referred to must be only apparent, and

that the tenacity actually exhibited at 572°, as well as that which prevails while the iron is in the state in which it was left by forging, or rolling, must be below its maximum tenacity."

From the experiments made upon several bars of the same iron, it appeared that their "maximum tenacity was 15 17 per cent. greater than their mean strength when tried cold."

Calculating the maximum tenacity in other experiments from this standard, the Sub-committee have drawn up the following Table exhibiting the relations between diminutions from the maximum tenacity and the degrees of temperature by which they are caused, from which the curve representing the law of these relations can be constructed.

TABLE.

No. of the comparison.	Observed temperatures.	Observed temperatures—80°.	Observed diminution of tenacity.	Power of the temperature which represents the diminution of tenacity at each point.
1	520°	440°	.0738	2.25
2	570	490	.0869	2.17
3	596	516	.0899	2.38
4	662	582	.1155	2.67
5	770	690	.1627	2.85
6	824	744	.2010	2.94
7	932	852	.3324	2.97
8	1030	950	.4478	2.92
9	1111	1031	.5514	2.63
10	1155	1075	.6000	2.60
11	1237	1157	.6622	2.41
12	1317	1237	.7001	2.14
				Mean 2.58

The Sub-committee remark on the construction of the above Table. "As some of the experiments which furnished the standards of comparison for strength at ordinary temperatures, were made at 80°, and as at this point small variations with respect to heat appear to affect but very slightly the tenacity of iron, it was conceived that for practical purposes, at least, the calculations might be commenced from that point."

"It will be found that with the exception of a slight anomaly between 520° and 570°, amounting to —.08, the numbers expressing the ratios between the elevations of temperature, and the diminutions of tenacity, constantly increase until we reach 932°, at which it is 2.97, and that from this point the ratio of diminution decreases to the limits of our range of trials, 1317°, where it is 2.14. It will also be observed, that the diminution of tenacity at 932°, where the law changes from an increasing to a decreasing

rate of diminution, is almost precisely one third of the total, or *maximum* strength of the iron at ordinary temperatures."

From the mean of all the rates in the above Table the following rule is deduced: "*the thirteenth power of the temperature above 80° is proportionate to the fifth power of the diminution from the maximum tenacity.*"

Professor W. R. Johnson, a member of the sub-committee, has since applied the results developed in the preceding experiments to practical purposes, in increasing the tenacity of wrought iron by subjecting it to tension under a high degree of temperature, before using it for purposes in which it will have to undergo considerable strains, as, for example, in chain cables, &c.

This subject was brought by Prof. Johnson before the Board of Navy Commissioners in 1841; subsequently, experiments were made by him under direction of the Navy Department, the results of which, as exhibited in the following Table, were published in the *Senate Public Documents*, (1) *28th Congress, 2d Session*, p. 641. Dec. 3, 1844.

Table of the effects of Thermo-tension on the Tenacity and Elongation of Wrought Iron.

KIND OF IRON.	Strength of cold.	Strength after treating with Thermo-tension.	Gain of length.	Gain of strength by the treatment.	Total gain of value.
Tredegar, No. 1, round iron	60	71.4	6.51	19.00	25.51
Do. do.	60	72.0	6.51	20.00	26.51
Tredegar, square bar iron	60	67.2	6.77	12.00	18.77
Tredegar, No. 3, round iron	58	68.4	5.263	17.93	23.19
Salisbury, round, (Ames')	105.87	121.0	3.73	14.29	18.02
Mean,	—	—	5.75	16.64	22.40

Prof. Johnson in his letter remarks: "It will be observed that in these experiments the temperature has, with a view to economy of time, been limited to 400°, whereas the best effects of the process have generally been obtained heretofore when the heat has been as high as 575°."

332. *Resistance of Iron Wire to Impact.* The following Table of experiments gives the results obtained by Mr. Hodgkinson, by suspending an iron ball at the end of a wire, (diameter No. 17,) and letting another iron ball impinge upon it from different altitudes. The suspended and impinging balls had holes drilled through them, through which the wire passed. A disc of lead was placed on the suspended ball to receive the blow, and lesser the recoil from elasticity.

TABLE.

Length of wire.	Weight of striking ball.	Weight of suspended ball and lead.	Height fallen through by striking ball.	Wire broke with ball falling through.	Remarks.
ft. in.	lbs. oz.	lbs. oz.			
25 0	5 14	0 9	2, 2½, 3, 3½, 4,	4½ } 4¾	No lead.
—	—	—	(repeated) 2½, 3, 3½, 4, 4½,	5 }	
24 0	6 0	10 1	7,	7 } 7	The wire usually broke near the point of impact, and it was adjusted to its length, if fresh wire were not used by a reserve at the top.
—	—	—	(repeated with fresh wire,) 6,	6½ }	
—	—	44 0	1, 2, 3, 4, 5, 6, 6½, 7,	7½	
—	—	80 8	6, 6½, 7, 7 , 8, 8 , 9,	9½	
—	—	89 0	8, 8 , 9, 9½, 10, 10½,	11	
—	—	125 0	8, 8 , 9, 9½, 10,	10½	
—	40 0	10 1	3, 4 inches,	5 inches	
—	—	80 8	2, 3, 4, 5, 6 inches,	7 do.	
—	—	89 0	4, 5 inches,	6 do.	Broke one inch from top.
24 8	85 0	44 0	2 inches,	3 do.	

The following observations are made by Mr. Hodgkinson: "To ascertain the strength and extensibility of this wire, it was broken in a very careful experiment with 252½ lbs., suspended at its lower end, and laid gradually on. And to obtain the increment of a portion of the wire (length 24 ft. 8 in.) when loaded by a certain weight, it had 139 lbs. hung at the bottom, and when 89 lbs. were taken off the load, the wire decreased in length .39 inch.

"Should it be suggested that the wire by being frequently impinged upon would perhaps be much weakened, the author would beg to refer to a paper of his on Chain Bridges, *Manchester Memoirs*, 2d series, vol. 5, where it is shown that an iron wire broken by pressure several times in succession is very little weakened, and will nearly bear the same weight as at first."

"The first of the preceding experiments on wires are the only ones from which the maximum can, with any approach to certainty, be inferred; and we see from them that the wire resisted the impulsion with the greatest effect when it was loaded at bottom with a weight, which, added to that of the striking body, was a little more than one third of the weight that would break the wire by pressure."

"From these experiments generally, it appears that the wire was weak to bear a blow when lightly loaded."

"These last experiments and remarks, and some of the preceding ones," (on horizontal impact,) "show clearly the benefit of giving considerable weight to elastic structures subject to impact and vibration."

333. *Resistance to Torsion of Wrought and Cast Iron.* The following Table exhibits the results of experiments made by Mr. Dunlop, at Glasgow, on round bars of wrought iron. The twisting weights were applied with an arm of lever 14 feet 2 inches.

Length of bars in inches.	Diameter of bars in inches.	Weight in lbs. producing rupture.
$2\frac{3}{4}$	2	250
$2\frac{1}{4}$	$2\frac{1}{4}$	384
3	$2\frac{1}{2}$	408
3	$2\frac{3}{4}$	700
4	$3\frac{1}{4}$	1170
5	$3\frac{1}{2}$	1240
5	$3\frac{3}{4}$	1662
5	4	1938
6	$4\frac{1}{4}$	2158

Table of experiments made by Mr. G. Rennie upcn Cast and Wrought Iron. Weight applied at an arm of leve1 of 2 feet.

MATERIAL.	Length of blocks in inches.	Size of sectional area.	Mean breaking weight in lbs.	
			lbs.	oz.
Iron cast horizontally	0	$\frac{1}{4}$	9	15
" vertically	0	$\frac{1}{4}$	10	10
" horizontally	$\frac{1}{4}$	$\frac{1}{4}$	7	3
" "	$\frac{3}{4}$	$\frac{1}{4}$	8	1
" "	1	$\frac{1}{4}$	8	8
" vertically	$\frac{1}{4}$	$\frac{1}{4}$	10	1
" "	$\frac{3}{4}$	$\frac{1}{4}$	8	9
" "	1	$\frac{1}{4}$	8	5
" "	6	$\frac{1}{4}$	9	12
" horizontally	0	$\frac{1}{2}$	93	12
" "	0	$\frac{1}{2}$	74	
" "	10	$\frac{1}{2}$	52	
Wrought iron, (*English*)	0	$\frac{1}{4}$	10	2
" (*Swedish*)	0	$\frac{1}{4}$	9	8

334. STRENGTH OF COPPER. The various uses to which copper is applied in constructions, render a knowledge of its resistance under various circumstances a matter of great interest to the engineer.

Resistance to Extension. The resistance of *cast* copper on the square inch, from the experiments of Mr. G. Rennie, is 8.51 tons, that of *wrought* copper reduced per hammer at 15.08 tons. Copper wire is stated to bear 27.30 tons on the square inch. From the experiments made under the direction of the *Franklin Institute*, already cited, the mean strength of rolled sheet copper is stated at 14.35 tons per square inch.

Resistance to Compression. Mr. Rennie's experiments on cubes of one fourth of an inch on the edge, give for the crushing

weight of cube of cast copper 7318 lbs., and of wrought copper 6440 lbs.

335. *Effects of Temperature on Tensile Strength.* The experiments already cited of the Franklin Institute, show that the difference in strength at the lower temperatures, as between 60° and 90°, is scarcely greater than what arises from irregularities in the structure of the metal at ordinary temperatures. At 550° Fahr. copper loses *one fourth* of its tenacity at ordinary temperatures, at 817° precisely *one half*, and at 1000° *two thirds*.

Representing the results of experiments by a curve of which the ordinates represent the temperatures above 32°, and the abscissas the diminutions of tenacity arising from increase of temperature, the relations between the two will be thus expressed: *the squares of the diminutions are as the cubes of the temperatures.*

336. STRENGTH OF OTHER METALS. Mr. Rennie states the tenacity of *cast* tin at 2.11 tons per square inch; and the resistance to compression of a small cube of ¼ of an inch on an edge at 966 lbs.

In the same experiments, the tenacity of *cast* lead is stated at 0.81 tons per square inch; and the resistance of a small cube of same size as in preceding paragraph at 483 lbs.

In the same experiments, the tenacity of hard gun-metal is stated at 16.23 tons; that of fine yellow brass at 8.01 tons. The resistance to compression of a cube of brass the same as before-mentioned, is stated at 10304 lbs.

337. *Linear Dilatation of Metals by Heat.* The following Table is taken from results of experiments on the dilatation of solids, by Professor Daniell, published in the *Philosophical Transactions*, 1831.

Table of Dimensions which a bar takes whose length at 62° is 1.0000.

	At 212°, (150°.)	At 662°, (600°.)	At point of fusion.
Iron, (wrought)	1.000984	1.004483	1.018378*
Iron, (cast)	1.000893	1.003943	1.016389
Zinc	1.002480	1.008527	1.012621
Copper	1.001430	1.006347	1.024376
Lead	1.002323	—	1.009072
Tin	1.001472	—	1.003798
Brass, (zinc ¼)	1.001787	1.007207	1.021841
Bronze, (tin ¼)	1.001541	1.007053	1.016336
Pewter, (tin ⅕)	1.001696	—	1.003776

* At fusing point of cast iron.

338. *Adhesion of Iron Spikes to Timber.* The following Tables and results are taken from an article, by Professor Walter R. Johnson, published in the *Journal of the Franklin Institute*, vol. 19, 1837, giving the details of experiments made by him on spikes of various forms driven into different kinds of timber.

339. The first series of experiments was made with Burden's plain square spike, the flanched, grooved, and swell spike, and the grooved and swelled spike. The timber was seasoned Jersey yellow pine, and seasoned white oak.

From these experiments it results, that the grooved and swelled form is about 5 per cent. less advantageous than the plain, in yellow pine, and about 18¼ per cent. superior to the plain in oak. The advantage of seasoned oak over the seasoned pine, for retaining plain spikes, is as 1 to 1.9, and for grooved spikes as 1 to 2.37.

340. The second series of experiments, in which the timber was soaked in water after the spikes were driven, gave the following results.

For swelled and grooved spikes, the order of retentiveness was, 1 locust; 2 white oak; 3 hemlock; 4 unseasoned chesnut; 5 yellow pine.

For grooved spike without swell, the like order is—1 unseasoned chesnut; 2 yellow pine; 3 hemlock.

The swelled and grooved spike was, in all cases, found to be inferior to the same spike with the swell filed off.

341. The third series of experiments gave the following results.

Thoroughly seasoned oak is *twice*, and thoroughly seasoned locust 2¾ times as retentive as unseasoned chesnut.

The forces required to extract spikes are more nearly proportional to the breadths than to either the thickness or the weights of the spikes. And, in some cases, a diminution of thickness with the same breadth of spike afforded a gain in retentiveness.

"In the softer and more spongy kinds of wood the fibres, instead of being forced back longitudinally and condensed upon themselves, are, by driving a thick, and especially a rather obtusely-pointed spike, folded in masses backward and downward so as to leave, in certain parts, the faces of the grain of the timber in contact with the surface of the metal."

"Hence it appears to be necessary, in order to obtain the greatest effect, that the fibres of the wood should press the faces as nearly as possible in their longitudinal direction, and with equal intensities throughout the whole length of the spike."

The following is the order of superiority of the spikes from that of the ratio of their weights and extracting forces respectively.

1. Narrow flat . . .	7.049	ratio of weight to	extracting	force
2. Wide flat . . .	5.712	"	"	
3. Grooved but not swelled	5.662	"	"	"
4. Grooved and not notched	5.300	"	"	"
5. Grooved and swelled .	4.624	"	"	"
6. Burden's patent . .	4.509	"	"	"
7. Square hammered . .	4.129	"	"	"
8. Plain cylindrical . .	3.200	"	"	"

"All the experiments prove that when a spike is once started, the force required for its final extraction is much less than that which produced the first movement."

"When a bar of iron is spiked upon wood, if the spike be driven until the bar compresses the wood to a great degree, the recoil of the latter may become so great as to start back the spike for a short distance after the last blow has been given."

342. From the fourth series of experiments it appears, that the spike tapering gradually towards the cutting edge, gives better results than those with more obtuse ends.

That beyond a certain limit the ratio of the weight of the spike to the extracting force begins to diminish; "showing that it would be more economical to increase the number rather than the length of the spikes for producing a given effect."

"That the absolute retaining power of unseasoned chesnut on square or flat spikes of from two to four inches in length, is a little more than 800 lbs. for every square inch of their two faces which condense longitudinally the fibres of the timber."

MASONRY.

343. MASONRY is the art of raising structures, in stone, brick, and mortar.

344. Masonry is classified either from the nature of the material, as *stone masonry*, *brick masonry*, and *mixed*, or that which is composed of stone and brick; or from the manner in which the material is prepared, as *cut stone* or *ashlar masonry*, *rubble stone* or *rough masonry*, and *hammered stone masonry;* or, finally, from the form of the material, as *regular masonry*, and *irregular masonry*.

345. *Cut Stone.* Masonry of cut stone, when carefully made, is stronger and more solid than that of any other class; but, owing to the labor required in *dressing*, or preparing the stone, it is also the most expensive. It is, therefore, mostly restricted to those works where a certain architectural effect is to be produced by the regularity of the masses, or where great strength is indispensable.

346. Before explaining the means to be used to obtain the greatest strength in cut stone, it will be necessary to give a few definitions to render the subject clearer.

In a wall of masonry, the term *face* is usually applied to the front of the wall, and the term *back* to the inside; the stone which forms the front, is termed the *facing;* that of the back, the *backing;* and the interior, the *filling*. If the front, or back of the wall, has a uniform slope from the top to the bottom, this slope is termed the *batter*, or *bâtir*.

The term *course* is applied to each horizontal layer of stone in the wall: if the stones of each layer are of equal thickness throughout, it is termed *regular coursing;* if the thicknesses are unequal, the term *random*, or *irregular coursing*, is applied. The divisions between the stones, in the courses, are termed the *joints;* the upper surface of the stones of each course is also, sometimes, termed the *bed*, or *build*.

The arrangement of the different stones of each course, or of contiguous courses, is termed the *bond*.

347. The strength of a mass of cut stone masonry will depend on the size of the blocks in each course; on the accuracy of the dressing; and on the bond used.

348. The size of the blocks varies with the kind of stone, and the nature of the quarry. From some quarries the stone may be obtained of any required dimensions; others, owing to some peculiarity in the formation of the stone, only furnish blocks of small

size. Again, the strength of some stones is so great as to admit of their being used in blocks of any size, without danger to the stability of the structure, arising from their breaking; others can only be used with safety, when the length, breadth, and thickness of the block bear certain relations to each other. No fixed rule can be laid down on this point: that usually followed by builders, is to make, with ordinary stone, the breadth at least equal to the thickness, and seldom greater than twice this dimension, and to limit the length to within three times the thickness. When the breadth or the length is considerable, in comparison with the thickness, there is danger that the block may break, if any unequal settling, or unequal pressure should take place. As to the absolute dimensions, the thickness is generally not less than one foot, nor greater than two; stones of this thickness, with the relative dimensions just laid down, will weigh from 1000 to 8000 pounds, allowing, on an average, 160 pounds to the cubic foot. With these dimensions, therefore, the weight of each block will require a very considerable power, both of machinery and men, to set it on its bed.

349. For the coping and top courses of a wall, the same objections do not apply to excess in length: but this excess may, on the contrary, prove favorable; because the number of top joints being thus diminished, the mass beneath the coping will be better protected, being exposed only at the joints, which cannot be made water-tight, owing to the mortar being crushed by the expansion of the blocks in warm weather, and, when they contract, being washed out by the rain.

350. The closeness with which the blocks fit is solely dependent on the accuracy with which the surfaces in contact, are wrought or *dressed;* if this part of the work is done in a slovenly manner, the mass will not only present open joints from any inequality in the settling; but, from the courses not fitting accurately on their beds, the blocks will be liable to crack from the unequal pressure on the different points of the block.

351. The surfaces of one set of joints should, as a prime condition, be perpendicular to the direction of the pressure: by this arrangement, there will be no tendency in any of the blocks to slip. In a vertical wall, for example, the pressure being downward, the surfaces of one set of joints, which are the beds, must be horizontal. The surfaces of the other set must be perpendicular to these, and, at the same time, perpendicular to the face, or to the back of the wall, according to the position of the stones in the mass; two essential points will thus be attained; the angles of the blocks, at the top and bottom of the course, and at the face or back, will be right angles, and the block will therefore be as strong as the nature of the stone will admit. The principles

here applied to a vertical wall, are applicable in all cases whatever may be the direction of the pressure and the form of the exterior surfaces, whether plane or curved.

352. A modification of this principle, however, may in some cases be requisite, arising from the strength of the stone. It is laid down as a rule, drawn from the experience of builders, that no stone work with angles less than 60° will offer sufficient strength and durability to resist accidents, and the effects of the weather. If, therefore, the batter of a wall should be greater than 60°, which is about 7 perpendicular to 4 base, the horizontal joints (Fig. 6) must not be carried out in the same plane, to the

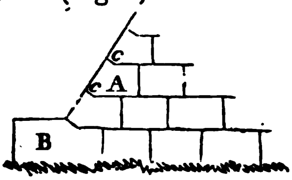


Fig. 6—Represents the arrangement of stone with abutting, or *elbow* joints for very inclined surfaces.
A, face of the block.
c, elbow joint.
B, buttress block, termed a *newell* stone.

face or back, but be broken off at right angles to it, so as to form a small abutting joint of about 4 inches in thickness. As the batter of walls is seldom so great as this, except in some cases of sustaining walls for the side slopes of earthen embankments, this modification in the joints will not often occur; for, in a greater batter, it will generally be more economical, and the construction will be stronger, to place the stones of the exterior in offsets, the exterior stone of one course, being placed within the exterior one of the course below it, so as to give the required general direction of the batter. The arrangement with offsets has the farther advantage in its favor of not allowing the rain water to lodge in the joint, if the offset be slightly bevelled off.

353. Workmen, unless narrowly watched, seldom take the pains necessary to dress the beds and joints accurately; on the contrary, to obtain what are termed *close joints*, they dress the joints



Fig 7—Represents a section of a wall in which the face is of cut stone, with the tails of the blocks thinned off, and the backing of rubble
A, section of face block.
B, rubble backing.

with accuracy a few inches only from the outward surface, and then chip away the stone towards the back, or *tail*, (Fig. 7,) so

that, when the block is set, it will be in contact with the adjacent stones, only through out this very small extent of bearing surface. This practice is objectionable under every point of view; for, in the first place, it gives an extent of bearing surface, which being generally inadequate to resist the pressure thrown on it, causes the block to splinter off at the joint; and in the second place, to give the block its proper set, it has to be propped beneath by small bits of stone, or wooden wedges, an operation termed *pinning-up*, or *under-pinning*, and these props, causing the pressure on the block to be thrown on a few points of the lower surface, instead of being equally diffused over it, expose the stone to crack.

354. When the facing is of cut stone, and the backing of rubble, the method of thinning off the block may be allowed for the purpose of forming a better bond between the rubble and ashlar; but, even in this case, the block should be dressed true on each joint, to at least one foot back from the face. If there exists any cause, which would give a tendency to an outward thrust from the back, then, instead of thinning off all the blocks towards the tail, it will be preferable to leave the tails of some thicker than the parts which are dressed.

355. Various methods are used by builders for the bond of cut stone. The system, termed *headers* and *stretchers*, in which the vertical joints of the blocks of each course alternate with the vertical joints of the courses above and below it, or as it is termed *break joints* with them, is the most simple, and offers, in most cases, all requisite solidity. In this system, (Fig. 8,) the blocks of each course are laid alternately with their greatest and least dimensions to the face of the wall; those which present the longest dimen-

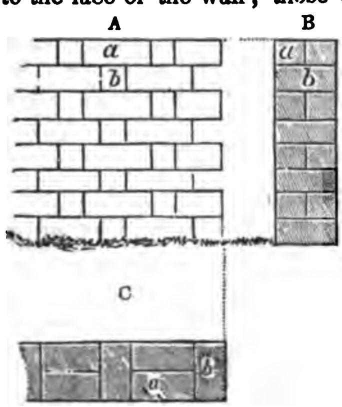


Fig. 8—Represents an elevation A, end view B, and plan C, of a wall arranged as headers and stretchers.
a, stretchers.
b, headers.

sion along the face, are termed stretchers; the others, headers. If the header reaches from the face to the back of the wall, it is

termed a *through;* if it only reaches part of the distance it is termed a *binder*. The vertical joints of one course are either just over the middle of the blocks of the next course below, or else, at least four inches on one side or the other of the vertical joints of that course; and the headers of one course rest as nearly as practicable on the middle of the stretchers of the course beneath. If the backing is of rubble, and the facing of cut stone, a system of throughs or binders, similar to what has just been explained, must be used.

By the arrangement here described, the facing and backing of each course are well connected; and, if any unequal settling takes place, the vertical joints cannot open, as would be the case were they in a continued line from the top to the bottom of the mass; as each block of one course confines the ends of the two blocks on which it rests in the course beneath.

356. In masses of cut stone exposed to violent shocks, as those of which light-houses, and sea-walls in very exposed positions are formed, the blocks of each course require to be not only very firmly united with each other, but also with the courses above and below them. To effect this, various means have been used. The beds of one course are sometimes arranged with projections (Fig. 9,) which fit into corresponding indentations of the next course. Iron cramps in the form of the letter S, or in any other

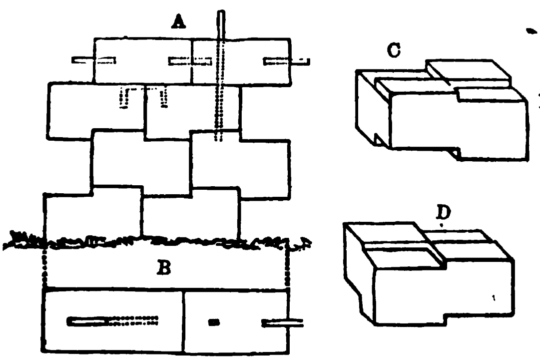


Fig. 9—Represents an elevation A, plan B, and perspective views C and D of two of the blocks of a wall in which the blocks are fitted with indents, and connected with bolts and cramps of metal.

shape that will answer the purpose of giving them a firm hold on the blocks, are let into the top of two blocks of the same course at a vertical joint, and are firmly set with melted lead, or with bolts, so as to confine the two blocks together. Holes are, in some cases, drilled through several courses, and the blocks of these courses are connected by strong iron bolts fitted to the holes.

The most noted examples of these methods of strengthening the bond of cut stone, are to be found in the works of the Romans

which have been preserved to our time, and in two celebrated modern structures, the Eddy-stone and Bell-rock light-houses in Great Britain. (Fig. 10.)

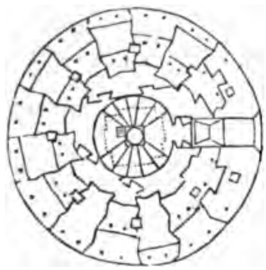


Fig. 10—Represents the manner of arranging stones of the same course by dove-tail joints and joggling, taken from a horizontal section of the masonry of the Bell-rock light-house.

357. The manner of dressing stone belongs to the stonecutter's art, but the engineer should not be inattentive either to the accuracy with which the dressing is performed, or the means employed to effect it. The tools chiefly used by the workman are the chisel, axe, and hammer for *knotting*. The usual manner of dressing a surface, is to cut draughts around and across the stone with the chisel, and then to use the chisel, the axe with a serrated edge, or the knotting hammer, to work down the intermediate portions into the same surface with the draughts. In performing this last operation, the chisel and axe should alone be used for soft stones, as the grooves on the surface of the hammer are liable to become choked by a soft material, and the stone may in consequence be materially injured by the repeated blows of the workman. In hard stones this need not be apprehended.

In large blocks which require to be raised by machinery, a hole, of the shape of an inverted truncated wedge, is cut to receive

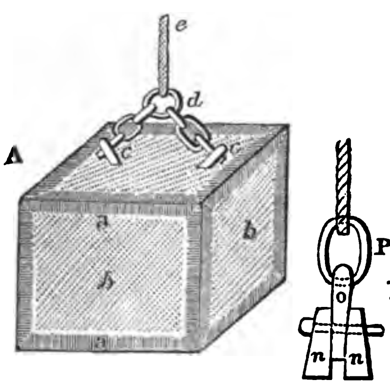


Fig. 11—Represents a perspective view A of a block of stone with draughts around the edges of its faces, and the intermediate space axed, or knotted, and its tackling for hoisting: also the common iron *lewis* B with its tackling.
a, draughts around edge of block.
b, knotted part between draughts.
c, iron bolts with eyes let into oblique holes cut in the block.
d and *e*, chain and rope tackling.
n, *n*, side pieces of the lewis.
o, centre piece of lewis with eye fastened to *n*, *n* by a bolt.
p, iron ring for attaching tackling.

a small iron instrument termed a *lewis*, (Fig. 11,) to which the rope is attached for suspending the block; or else two holes are

cut obliquely into the block to receive bolts with eyes for the same purpose.

When a block of cut stone is to be laid, the first point to be attended to, is to examine the dressing, which is done by placing the block on its bed, and seeing that the joints fit close, and the face is in its proper plane. If it be found that the fit is not accurate, the inaccuracies are marked, and the requisite changes made. The bed of the course, on which the block is to be laid, is then thoroughly cleansed from dust, &c., and well moistened, a bed of thin mortar is laid evenly over it, and the block, the lower surface of which is first cleansed and moistened, is laid on the mortar-bed, and well settled by striking it with a wooden mallet. When the block is laid against another of the same course, the joint between them is prepared with mortar in the same manner as the bed.

358. *Rubble Stone Masonry.* With good mortar, rubble work, when carefully executed, possesses all the strength and durability required in structures of an ordinary character; and it is much less expensive than cut stone.

359. The stone used for this work should be prepared simply by knocking off all the sharp, weak angles of the block; it is then cleansed from dust, &c., and moistened, before placing it on its bed. This bed is prepared by spreading over the top of the lower course an ample quantity of good ordinary-tempered mortar, into which the stone is firmly imbedded. The interstices between the larger masses of stone are filled in, by thrusting small fragments, or chippings of stone, into the mortar. Finally, the whole course may be carefully grouted before another is commenced, in order to fill up any voids left between the full mortar and stone.

360. To connect the parts well together, and to strengthen the weak points, throughs or binders should be used in all the courses; and the angles should be constructed of cut or hammered stone. In heavy walls of rubble masonry, the precaution, moreover, should be observed, to lay the stones on their *quarry-bed;* that is, to give them the same position, in the mass of masonry, that they had in the quarry; as stone is found to offer more resistance to pressure in a direction perpendicular to the quarry-bed, than in any other. The directions of the lamina in stratified stones, show the position of the quarry-bed.

361. Hammered stone, or dressed rubble, is stone roughly fashioned into regular masses with the hammer. The same precautions must be taken in laying this kind of masonry, as in the two preceding.

362. *Brick Masonry.* With good brick and mortar, this masonry offers great strength and durability, arising from the strong adhesion between the mortar and brick.

363. The bond used in brick work is very various, depending on the character of the structure. The most usual kinds are known as the *English* and *Flemish.* The first consists in arranging the courses alternately, entirely as headers or stretchers, the bricks through the course breaking joints. In the second the bricks are laid as headers and stretchers in each course. The first is stated to give a stronger bond than the last, the bricks of which, owing to the difficulty of preventing continuous joints, either in the same or different courses, are liable to separate, causing the face or the back to bulge outward. The Flemish bond presents the finer architectural appearance, and is therefore preferred for the fronts of edifices.

364. Timber and iron have both been used to strengthen the bond of brick masonry. Among the most remarkable examples of their uses are the well, faced in brick, forming an entrance to the Thames Tunnel, the celebrated work of Mr. Brunel, and his experimental arch of brick, a description of which is given in the *Civil Engineer and Architect's Journal*, No. 6, vol. I. In both these structures Mr. Brunel used pantile laths and hoop iron, in the interior of the horizontal courses, to connect two contiguous courses throughout their length. The efficacy of this method has been farther fully tested by Mr. Brunel, in experiments made on the resistance to a transversal strain of a brick beam bonded with hoop iron, accounts of which, and of experiments of a like kind, are given by Colonel Pasley in his work on *Limes, Calcareous Cements*, &c.

365. The mortar-bed of brick, may be either of ordinary, or thin-tempered mortar; the last, however, is the best, as it makes closer joints, and, containing more water, does not dry so rapidly as the other. As brick has great avidity for water, it would always be well not only to moisten it before laying it, but to allow it to soak in water several hours before it is used. By taking this precaution, the mortar between the joints will set more firmly than when it imparts its water to the dry brick, which it frequently does so rapidly as to render the mortar pulverulent when it has dried.

FOUNDATIONS.

366. The term *foundation* is used indifferently either for the lower courses of a structure of masonry, or for the artificial arrangement, of whatever character it may be, on which these courses rest. For more perspicuity, the term *bed of the foundation* will be used in this work when the latter is designated.

367. The strength and durability of structures of masonry depend essentially upon the bed of the foundation. In arranging this, regard must be had not only to the permanent efforts which

the bed may have to support, but to those of an accidental character. It should, in all cases, be placed so far below the surface of the soil on which it rests, that it will not be liable to be uncovered, or exposed; and its surface should not only be normal to the resultant of the efforts which it sustains, but this resultant should intersect the base of the bed so far within it, that the portion of the soil between this point of intersection and the outward edge of the base shall be broad enough to prevent its yielding from the pressure thrown on it.

368. The first preparatory step to be taken, in determining the kind of bed required, is to ascertain the nature of the subsoil on which the structure is to be raised. This may be done, in ordinary cases, by sinking a pit; but where the subsoil is composed of various strata, and the structure demands extraordinary precaution, borings must be made with the tools usually employed for this purpose.

369. With respect to foundations, soils are usually divided into three classes:

The 1st class consists of soils which are incompressible, or, at least, so slightly compressible, as not to affect the stability of the heaviest masses laid upon them, and which, at the same time, do not yield in a lateral direction. Solid rock, some tufas, compact stony soils, hard clay which yields only to the pick, or to blasting, belong to this class.

The 2d class consists of soils which are incompressible, but require to be confined laterally, to prevent them from spreading out. Pure gravel and sand belong to this class.

The 3d class consists of all the varieties of compressible soils; under which head may be arranged ordinary clay, the common earths, and marshy soils. Some of this class are found in a more or less compact state, and are compressible only to a certain extent, as most of the varieties of clay and common earth; others are found in an almost fluid state, and yield, with facility, in every direction.

370. To prepare the bed for a foundation on rock, the thickness of the stratum of rock should first be ascertained, if there are any doubts respecting it: and if there is any reason to suppose that the stratum has not sufficient strength to bear the weight of the structure, it should be tested by a trial weight, at least twice as great as the one it will have to bear permanently. The rock is next properly prepared to receive the foundation courses, by levelling its surface, which is effected by breaking down all projecting points, and filling up cavities, either with rubble masonry or with beton, and by carefully removing any portions of the upper stratum which present indications of having been injured by the weather. The surface, prepared in this manner, should, more

over, be perpendicular to the direction of the pressure; if this is vertical, the surface should be horizontal, and so for any other direction of the pressure. Should there, however, be any difficulty in so arranging the surface as to have it normal to the resultant of the pressure, it may receive a position such that one component of the resultant shall be perpendicular to it, and the other parallel; the latter being counteracted by the friction and adhesion between the base of the bed and the surface of the rock. If, owing to a great declivity of the surface, the whole cannot be brought to the same level, the rock must be broken into steps, in order that the bottom courses of the foundation throughout, may rest on a surface perpendicular to the direction of the pressure. If fissures or cavities are met with, of so great an extent as to render the filling them with masonry too expensive, an arch must then be formed, resting on the two sides of the fissure, to support that part of the structure above it.

The slaty rocks require most care in preparing them to receive a foundation, as their top stratum will generally be found injured to a greater or less depth by the action of frost.

371. In stony earths and hard clay, the bed is prepared by digging a trench wide enough to receive the foundation, and deep enough to reach the compact soil which has not been injured by the action of frost: a trench from 4 to 6 feet, will generally be deep enough for this purpose.

372. In compact gravel, and sand, where there is no liability to lateral yielding, either from the action of rain or any other cause, the bed may be prepared as in the case of stony earths. If there is danger from lateral yielding, the part on which the foundation is to rest must be secured by confining it laterally by means of sheeting piles, or in any other way that will offer sufficient security.

373. In laying foundations on firm sand, a further precaution is sometimes resorted to, of placing a platform on the bottom of the trench, for the purpose of distributing the whole weight more uniformly over it. This, however, seems to be unnecessary; for if the bottom courses of the masonry are well settled in their bed, there is no good reason to apprehend any unequal settling from the effect of the superincumbent weight: whereas, if the wood of the platform should, by any accident, give way, it would leave a part of the foundation without any support.

When the sand under the bed is liable to injury from springs they must be cut off, and a platform, or, still better, an area of beton should compose the bed, and this should be confined on all sides between walls of stone, or beton sunk below the bottom of the bed.

374. If, in opening a trench in sand, water is found at a slight

depth, and in such quantity as to impede the labors of the workmen and the trench cannot be kept dry by the use of pumps or scoops, a row of sheeting piles must be driven on each side of the space occupied by it, somewhat below the bottom of the bed, the sand on the outside of the sheeting piles be thrown out, and its place filled with a puddling of clay, to form a water-tight enclosure round the trench. The excavation for the bed is then commenced; but if it be found that the water still makes rapidly at the bottom, only a small portion of the trench must be opened, and after the lower courses are laid in this portion, the excavation will be gradually effected, as fast as the workmen can execute the work without difficulty from the water.

375. The beds of foundations in compressible soils require peculiar care particularly when the soil is not homogeneous, presenting more resistance to pressure in one point than in another; for, in that case, it will be very difficult to guard against unequal settling.

376. In ordinary clay, or earth, a trench is dug of the proper width, and deep enough to reach a stratum, beyond the action of frost; the bottom of the trench is then levelled off to receive the foundation. This may be laid immediately on the bottom, or else upon a *grillage* and *platform*. In the first case, the stones forming the lowest course, should be firmly settled in their beds, by ramming them with a very heavy beetle. In the second a timber grating, termed a grillage (Fig. 12,) which is formed of a course of heavy beams laid lengthwise in the trench, and connected firmly by cross pieces into which they are notched, is firmly settled in the bed, and the earth is solidly packed between the longitudinal and cross pieces; a flooring of thick planks, termed a platform, is then laid on the gridage, to receive the lowest course of the foundation. The object of the grillage, and

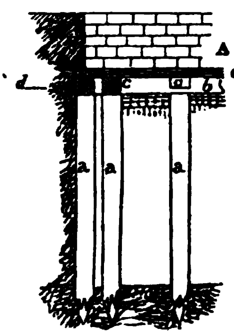


Fig. 19—Represents the arrangement of a millage and platform fitted on piles.
A, masonry.
aa, piles.
b, string pieces.
c, cross pieces.
d, capping piece.
e, platform of plank.

platform, is to diffuse the weight more uniformly over the surface of the trench, to prevent any part from yielding.

377. Repeated failures in grillages and platforms, arising either from the compression of the woody fibre, or from a transversal strain occasioned by the subsoil offering an unequal resistance, have impaired confidence in their efficacy. Engineers now prefer beds formed of an area of beton, as offering more security than any bed of timber, either in a uniformly, or unequally compressible soil.

378. The preparation of an area of beton for the bed of a foundation, will depend on the circumstances of the case. In ordinary cases the beton is thrown into the trench, and carefully rammed in layers of 6 or 9 inches, until the mortar collects in a semi-fluid state on the top of the layer. If the base of the bed is to be broader than the top, its sides must be confined by boards suitably arranged for this purpose. Whenever a layer is left incomplete at one end, and another is laid upon it, an offset should be left at the unfinished extremity, for the purpose of connecting the two layers more firmly when the work on the unfinished part is resumed.

Considerable economy may be effected, in the quantity of beton required for the bed, by using large blocks of stone which should be so distributed throughout the layer, that the beetle will meet with no difficulty in settling the beton between and around the blocks.

When springs rise through the soil over which the beton is to be spread, the water from them must either be conveyed off by artificial channels, which will prevent it rising through the mass of beton and washing out the lime; or else strong cloth, prepared so as to be impermeable to water, may be laid over the surface of the soil to receive the bed of beton.

The artificial channels for conveying off the water may be formed either of stone blocks with semi-cylindrical channels cut in them, or of semi-cylinders of iron, or tiles, as may be most convenient. A sufficient number of these channels should be formed to give an outlet to the water as fast as it rises.

An impermeable cloth may be formed of stout canvass, prepared with bituminous pitch and a drying oil. It is well to have the cloth doubled on each side with ordinary canvass to prevent accidents. The manner of settling the cloth on the surface of the soil must depend on the circumstances of the case.

Each of the foregoing expedients for preventing the action of springs on an area of beton, has been tried with success. When artificial channels are used, they may be completely choked subsequently, by injecting into them a semi-fluid hydraulic cement, and the action of the springs be thus destroyed.

Foundation beds of beton are frequently made without exhausting the water from the area on which they are laid. For this

purpose the beton is thrown in layers over the area, by using either a wooden conduit reaching nearly to the position of the layer, or else by placing the beton (Fig 13) in a box by which it is lowered to the position of the layer, and from which it is de posited so as not to pèrmit the water to separate the lime from the other ingredients.

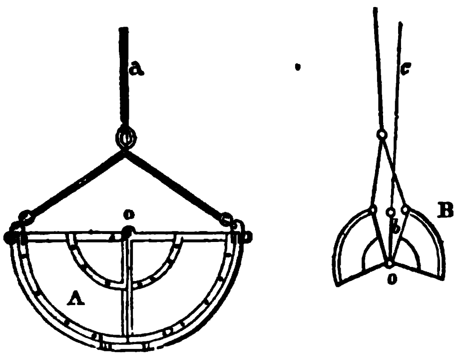


Fig. 13—Represents an end view A of a semi-cylindrical box for lowering beton in water, and B the same view of the box when opened to let the beton fall through.
o, hinge around which the halves of the box open.
a, rope tackling for lowering box.
b, pin, or catch to fasten the two parts of the box.
c, cord to detach the pin and open the box.

Should it be found that springs boil up at the bottom, it must be covered with an impermeable cloth.

379. In marshy soils, the principal difficulty consists in forming a bed sufficiently firm to give stability to the structure, owing to the yielding nature of the soil in all directions.

The following are some of the dispositions that have been tried with success in this case. Short piles from 6 to 12 feet long, and from 6 to 9 inches in diameter, are driven into the soil as close together as they can be crowded, over an area considerably greater than that which the structure is to occupy. The heads of the piles are accurately brought to a level to receive a grillage and platform; or else a layer of clay, from 4 to 6 feet thick, is laid over the area thus prepared with piles, and is either solidly rammed in layèrs of a foot thick, or submitted to a very heavy pressure for some time before commencing the foundations. The object of preparing the bed in this manner, is to give the upper stratum of the soil all the firmness possible, by subjecting it to a strong compression from the piles; and when this has been effected, to procure a firm bed for the lowest course of the foundation by the grillage, or clay bed; by these means the whole pressure will be uniformly distributed throughout the entire area. This case is also one in which a bed of beton would replace, with great advantage, either the one of clay, or the grillage.

The purposes to which the short piles are applied in this case is different from the object to be attained usually in the employ

ment of piles for foundations; which is to transmit the weight of the structure that rests on the piles, to a firm incompressible soil, overlaid by a compressible one, that does not offer sufficient firmness for the bed of the foundation.

380. When a firm soil is overlaid by one of a compressible character, and its distance below the surface is such that it can be reached by piles of ordinary dimensions, they should be used in preference to any other plan, when they can be rendered durable, on account of their economy and the security they afford.

To prepare the bed to receive the foundations in this case, strong piles are driven at equal distances apart, over the entire area on which the structure is to rest. These piles are driven, until they meet with a firm stratum below the compressible one, which offers sufficient resistance to prevent them from penetrating farther.

381. Piles are generally from 9 to 18 inches in diameter, with a length not above 20 times the diameter, in order that they may not bend under the stroke of the ram. They are prepared for driving, by stripping them of their bark, and paring down the knots, so that the friction, in driving, may be reduced as much as possible. The head of the pile is usually encircled by a strong hoop of wrought iron, to prevent the pile from being split by the action of the ram. The foot of the pile may receive a *shoe* formed of ordinary boiler iron, well fitted and spiked on; or a cast-iron shoe of a suitable form for penetrating the soil may be cast around a wrought-iron bolt, by means of which it is fastened to the pile.

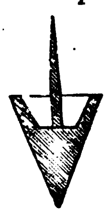


Fig. 14—Represents a section through the axis of a cast-iron shoe and wrought-iron bolt for a pile

382. A machine, termed a *pile engine*, is used for driving piles. It consists essentially of two uprights firmly connected at top by a cross piece, and of a *ram*, or *monkey* of cast iron, for driving the pile by a force of percussion. Two kinds of engines are in use; the one termed a *crab engine*, from the machinery used to hoist the ram to the height from which it is to fall on the pile; the other the *ringing engine*, from the monkey being raised by the sudden pull of several men upon a rope, by which the ram is drawn up a few feet to descend on the pile.

The crab engine is by far the more powerful machine, but on

this account is inapplicable in some cases, as in the driving of cast-iron piles, where the force of the blow might destroy the pile; also in long slender piles it may cause the pile to spring so much as to prevent it from entering the subsoil.

The manner of driving piles, and the extent to which they may be forced into the subsoil, will depend on local circumstances. It sometimes happens that a heavy blow will effect less than several slighter blows, and that piles after an interval between successive volleys of blows, can with difficulty be started at first. In some cases the pile breaks below the surface, and continues to yield to the blows, by the fibres of the lower extremity being crushed. These difficulties require careful attention on the part of the engineer. Piles should be driven to an unyielding subsoil. The French civil engineers have, however, adopted a rule to stop the driving when the pile has arrived at its *absolute stoppage*, this being measured by the farther penetration into the subsoil of about $\frac{2}{10}$ths of an inch, caused by a volley of thirty blows from a ram of 800 lbs., falling from a height of 5 feet at each blow.

383. If the head of a pile has to be driven below the level to which the ram descends, another pile, termed a *punch*, is used for the purpose. A cast-iron socket of a suitable form embraces the head of the pile and the foot of the punch, and the effect of the blow is thus transmitted through the punch to the pile.

384. When a pile from breaking, or any other cause, has to be drawn out, it is done by using a long beam as a lever for the purpose; the pile being attached to the lever by a chain, or rope suitably adjusted.

385. The number of piles required, will be regulated by the weight of the structure. An allowance of 1000 pounds on each square inch will ensure safety. The least distance apart, at which the piles can be driven with ease, is about $2\frac{1}{2}$ feet between their centres. If they are more crowded than this, they may force each other up, as they are successively driven. When this is found to take place, the driving should be commenced at the centre of the area, and the pile should be driven with the butt end downward.

386. From experiments carefully made in France, it appears that piles which resist only in virtue of the friction arising from the compression of the soil, cannot be subjected with safety to a load greater than one fifth of that which piles of the same dimensions will safely support when driven into a firm soil.

387. After the piles are driven, they are sawed off to a level, to receive a grillage and platform for the foundation. A large beam, termed a *capping*, is first placed on the heads of the outside row of piles, to which it is fastened by means of wooden

pins, or *tree-nails* driven into an auger-hole, made through the cap into the head of each pile. After the cap is fitted, longitudinal beams, termed *string pieces*, are laid lengthwise on the heads of each row, and rest at each extremity on the cap, to which they are fastened by a dove-tail joint and a wooden pin. Another series of beams, termed *cross pieces*, are laid crosswise on the string pieces, over the heads of each row of piles. The cross and string pieces are connected by a notch cut into each, so that, when put together, their upper surfaces may be on the same level, and they are fastened to the heads of the piles in the same manner as the capping. The extremities of the cross pieces rest on the capping, and are connected with it, like the string pieces.

The platform is of thick planks laid over the grillage, with the extremity of each plank resting on the capping, to which, and to the string and cross pieces, the planks are fastened by nails.

The capping is usually thicker than the cross and string pieces by the thickness of the plank; when this is the case, a rabate, about four inches wide, must be made on the inner edge of the capping, to receive the ends of the planks.

388. An objection is made to the platform as a bed for the foundation, owing to the want of adhesion between wood and mortar; from which, if any unequal settling should take place, the foundations would be exposed to slide off the platform. To obviate this, it has been proposed to replace the grillage and platform by a layer of beton resting partly on the heads of the piles, and partly on the soil between them. This means would furnish a firm bed for the masonry of the foundations, devoid of the objections made to the one of timber.

To counteract any tendency to sliding, the platform may be inclined if there is a lateral pressure, as in the case, for example, of the abutments of an arch.

389. In soils of alluvial formation, it is common to meet with a stratum of clay on the surface, underlaid with soft mud, in which case, the driving of short piles would be injurious, as the tenacity of the stratum of clay would be destroyed by the operation. It would be better not to disturb the upper stratum in this case, but to give it as much firmness as possible, by ramming it with a heavy beetle, or by submitting it to a heavy pressure.

390. Piles and sheeting piles of cast iron have been used with complete success in England, both for the ordinary purposes of cofferdams, and for permanent structures for wharfing. The piles have been cast of a variety of forms; in some cases they have been cast hollow for the purpose of excavating the soil within the pile as it was driven, and thus facilitate its penetration

into the subsoil. Fig. 15 represents a cross section of one of the more recent arrangements of iron piles and sheeting piles.

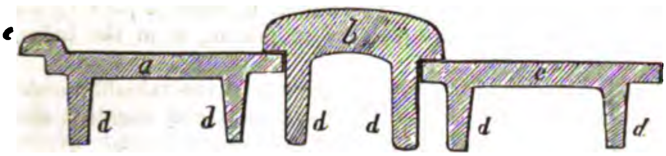


Fig. 15—Represents a horizontal section of an arrangement of piles and sheeting piles of cast iron.
a, sheeting pile with a lap e to cover the joint between it and the next sheeting pile.
b, piles with a lap on each side.
c, sheeting pile lapped by pile and sheeting pile next it.
d, ribs of piles and sheeting piles.

391. Sand has also been used with advantage to form a bed for foundations in a very compressible soil. For this purpose a trench is (Fig. 16) excavated, and filled with sand; the sand being spread in layers of about 9 inches, and each layer being firmly settled by a heavy beetle, before laying the next. If water

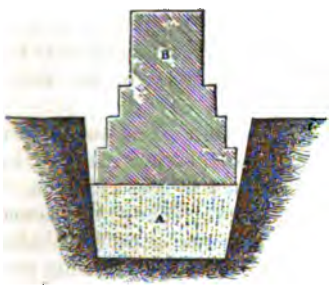


Fig. 16—Represents a section of a sand foundation bed and the masonry upon it.
A, sand bed in a trench.
B, masonry.

should make rapidly in the trench, it would not be practicable to pack the sand in layers. Instead, therefore, of opening a trench,

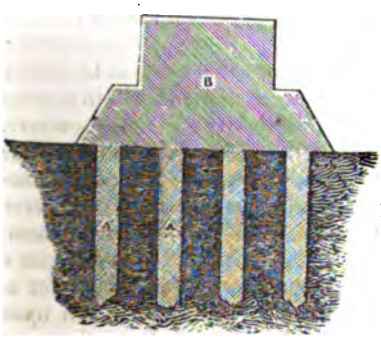


Fig. 17—Represents a section of a foundation bed made by filling holes with sand.
A, holes filled with sand.
B, masonry.

holes about 6 feet deep, and 6 inches in diameter, (Fig. 17,)

should be made, by means of a short pile, as close together as practicable; when the pile is withdrawn from the hole, it is immediately filled with sand. To cause the sand to pack firmly, it should be slightly moistened before placing it in the holes, or trench.

Sand, when used in this way, possesses the valuable property of assuming a new position of equilibrium and stability, should the soil on which it is laid yield at any of its points. Not only does this take place along the base of the sand bed, but also along the edges, or sides, when these are enclosed by the sides of the trench made to receive the bed. This last point offers also some additional security against yielding in a lateral direction. The bed of sand must, in all cases, receive sufficient thickness to cause the pressure on its upper surface to be distributed over the entire base.

392. When, from the fluidity of the soil, the vertical pressure of the structure causes the soil to rise around the bed, this action may be counteracted, either by scooping out the soil to some depth around the bed and replacing it by another of a more compact nature, well rammed in layers, or with any rubbish of a solid character; or else a mass of loose stone may be placed over the surface exterior to the bed, whenever the character of the structure will warrant the expense.

393. *Precautions against Lateral Yielding.* The soils which have been termed compressible, strictly speaking, yield only by the displacement of their particles either in a lateral direction, or upward around the structure laid upon them. Where this action arises from the effect of a vertical weight, uniformly distributed over the base of the bed, the preceding methods for giving permanent stability to structure, present all requisite security. But when the structure is subjected also to a lateral pressure, as for example, that which would arise from the action of a bank of earth resting against the back of a wall, additional means of security are demanded.

One of the most obvious expedients in this case, is to drive a row of strong square piles in juxtaposition immediately in contact with the exterior edges of the bed. This expedient is, however, only of service where the piles attain either an incompressible soil, or one at least firmer than that on which the bed immediately rests. For otherwise, as is obvious, the piles only serve to transmit the pressure to the yielding soil in contact with them. But where they are driven into a firm soil below, they gain a fixed point of resistance, and the only insecurity they offer is either by the rupture of the piles, from the cross strain upon them, or from the yielding of the firm subsoil, from the same cause

In case the piles reach a firm subsoil, it will be best to scoop out the upper yielding soil before driving the piles and to fill in between and around them with loose broken stone, (Fig. 18.) This will give the piles greater stiffness, and effectually prevent them from spreading at top.

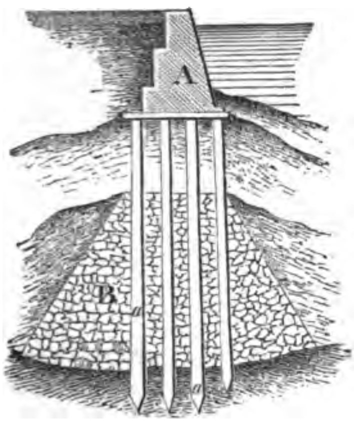


Fig. 18—Represents the manner of using loose stone to sustain piles and prevent them from yielding laterally.
A, section of the masonry.
B, loose stone thrown around the piles a

When the piles cannot be secured by attaining a firm subsoil it will be better to drive them around the area at some distance from the bed, and, as a farther precaution, to place horizontal buttresses of masonry at regular intervals from the bed to the piles. By this arrangement, some additional security is gained from the counter-pressure of the soil enclosed between the bed and the wall of piles. But it is obvious that unless the piles in this case are driven into a firmer soil than that on which the structure rests, there will still be danger of yielding.

In using horizontal buttresses, the stone of which they are constructed should be dressed with care; their extremities near the wall of piles should be connected by horizontal arches, (Fig. 19,) to distribute the pressure more uniformly; and where there is an upward pressure of the soil around the structure, arising from its weight, the buttresses ought to be in the form of reversed arches.

In buttresses of this kind, as likewise in broad areas resting on a very yielding soil, since as much danger is to be apprehended from their breaking by their own weight as from any other cause, it must be carefully guarded against. Something may be done for this purpose by ramming the earth around the structure with a heavy beetle, when it can be made more compact by this means; or else a part of the upper soil may be removed, and be replaced by one of a more compact nature which may be rammed in layers

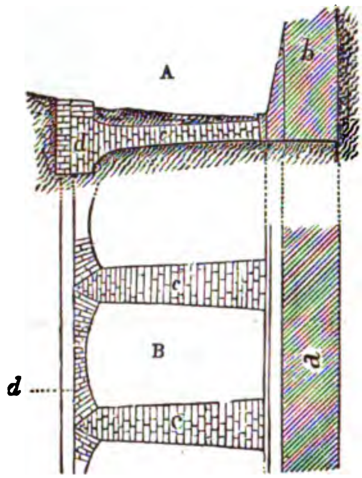


Fig. 19—Represents the manner of preventing a sustaining wall from yielding laterally to a thrust behind it, by using horizontal buttresses of reversed arches abutting against vertical counter arches.
A, vertical section of wall, buttresses, and counter arches.
B, plan of wall, buttresses, and counter arches.
a, plan of wall.
b, section of do
c, buttresses.
d, counter arches.

The following methods, where they can be resorted to, and where the character of the structure will justify the expense, have been found to offer the best security in the case in question.

When the bed can be buttressed in front with an embankment, a low counter-wall (Fig. 20) may be built parallel to the edge of the bed, and some 10 or 12 feet from it; between this wall and the bed a reversed arch connecting the two may be built, and a surcharge of earth of a compact character and well rammed, may be placed against the counter wall to act by its counter pressure against the lateral pressure upon the bed.

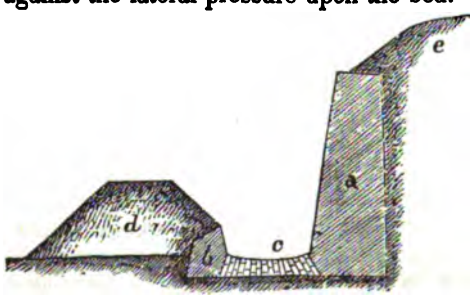


Fig. 20—Represents the manner of buttressing a sustaining wall in front by the action of a counter pressure of earth transmitted to the wall by a reversed arch.
a, section of sustaining wall.
b, section of sustaining wall of embankment *d*.
c, section of reversed arch.
d, section of embankment from which counter pressure comes.
e, section of embankment behind sustaining wall.

When the bed cannot be buttressed in front, as in quay walls, a grillage and platform supported on piles (Fig. 21) may be built to the rear from the back of the wall, for the purpose of supporting the embankment against the back of the wall, and preventing the effect which its pressure on the subsoil might have in thrusting forward the bed of the foundation.

In addition to these means, land ties of iron will give great ad

ditional security, when a fixed point in rear of the wall can be found to attach them firmly.

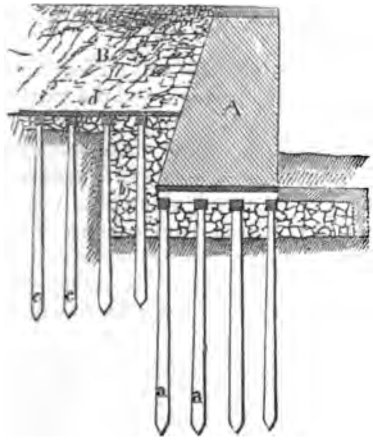


Fig. 21—Represents the manner of relieving a sustaining wall from the lateral action caused by the pressure of an embankment on the subsoil by means of a platform built behind the wall.
A, section of the wall.
B, section of embankment.
a, piles supporting the grillage and platform of A.
b, loose stone forming a firm bed under the platforms.
c, piles supporting the platform *d* behind the wall

394. *Foundations in Water*. In laying foundations in water, two difficulties have to be overcome, both of which require great resources and care on the part of the engineer. The first is found in the means to be used in preparing the bed of the foundation; and the second, in securing the bed from the action of the water, to ensure the safety of the foundations. The last is, generally, the more difficult problem of the two; for a current of water will gradually wear away, not only every variety of loose soils, but also the more tender rocks, such as most varieties of sand-stone, and the calcareous and argillaceous rocks, particularly when they are stratified, or are of a loose texture.

395. To prepare the bed of a foundation in stagnant water, the only difficulty that presents itself is to exclude the water from the area on which the structure is to rest. If the depth of water is not over 4 feet, this is done by surrounding the area with an ordinary water-tight dam of clay, or of some other binding earth. For this purpose, a shallow trench is formed around the area, by removing the soft, or loose stratum on the bottom; the foundation of the dam is commenced by filling this trench with the clay, and the dam is made by spreading successive layers of clay about one foot thick, and pressing each layer as it is spread, to render it more compact. When the dam is completed, the water is pumped out from the enclosed area, and the bed for the foundation is prepared as on dry land.

396. When the depth of stagnant water is over 4 feet, and in running water, of any depth, the ordinary dam must be replaced by the coffer-dam. This construction consists of two rows of

plank, termed *sheeting piles*, driven into the soil vertically, forming thus a coffer work, between which clay or binding earth, termed the *puddling*, is filled in, to form a water-tight dam to exclude the water from the area enclosed.

The arrangement, construction, and dimensions of coffer dams depend on their specific object, the depth of water, and the nature of the subsoil on which the coffer-dam rests.

With regard to the first point, the width of the dam between the sheeting piles should be so regulated as to serve as a scaffolding for the machinery and materials required about the work. This is peculiarly requisite where the coffer-dam encloses an isolated position removed from the shore. The interior space enclosed by the dam should have the requisite capacity for receiving the bed of the foundations, and such materials and machinery as may be required within the dam.

The width, or thickness of the coffer-dam, by which is understood the distance between the sheeting piles, should be sufficient not only to be impermeable to water, but to form, by the weight of the puddling, in combination with the resistance of the timber work, a wall of sufficient strength to resist the horizontal pressure of the water on the exterior, when the interior space is pumped dry. The resistance offered by the weight of the puddling to the pressure of the water can be easily calculated; that offered by the timber work will depend upon the manner in which the framing is arranged, and the means taken to *stay*, or buttress the dam from the enclosed space.

The most simple and the usual construction of a coffer-dam

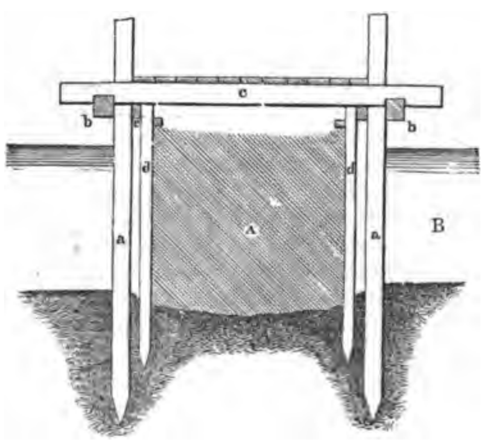


Fig. 22—Represents a section of the ordinary coffer-dam.
a, main piles.
b, wale, or string pieces.
c, cross pieces.
d, sheeting piles.
e, guide string pieces for sheeting piles.
A, puddling.
B, interior space.

(Fig. 22) consists in driving a row of ordinary straight piles around the area to be enclosed, placing their centre lines about 4

feet asunder. A second row is driven parallel to the first, the respective piles being the same distance apart; the distance between the centre lines of the two rows being so regulated as to leave the requisite thickness between the sheeting piles for the dam. The piles of each row are connected by a horizontal beam of square timber, termed a *string* or *wale piece*, placed a foot or two above the highest water line, and notched and bolted to each pile. The string pieces of the inner row of piles is placed on the side next to the area enclosed, and those of the outer row on the outside. Cross beams of square timber connect the string pieces of the two rows, upon which they are notched, serving both to prevent the rows of piles from spreading from the pressure that may be thrown on them, and as a joisting for the scaffolding. On the opposite sides of the rows, interior string pieces are placed, about the same level with the exterior, for the purpose of serving both as guides and supports for the sheeting piles. The sheeting piles being well jointed, are driven in juxtaposition, and against the interior string pieces. A third course of string, or *ribbon* pieces of smaller scantling confine, by means of large spikes, the sheeting piles against the interior string pieces.

As has been stated, the thickness of the dam and the dimensions of the timber of which the coffer work is made, will depend upon the pressure due to the head of water, when the interior space is pumped dry. For extraordinary depths, the engineer would not act prudently were he to neglect to verify by calculation the equilibrium between the pressure and resistance; but for ordinary depths under 10 feet, a rule followed is to make the thickness of the dam 10 feet; and for depths over 10 feet to give an additional thickness of one foot for every additional depth of three feet. This rule will give every security against filtrations through the body of the dam, but it might not give sufficient strength unless the scantling of the coffer work were suitably increased in dimensions.

In very deep tidal water, coffer-dams have been made in offsets, by using three rows of sheeting piles for the purpose of giving greater thickness to the dam below the low-water level. In such cases strong square piles closely jointed and tongued and grooved, should be used in place of the ordinary sheeting piles.

Besides providing against the pressure of the head of water, suitable dimensions must be given to the sheeting piles, in order that they may sustain the pressure arising from the puddling when the interior space is emptied of water. This pressure against the interior sheeting piles may be farther increased by that of the exterior water upon the exterior sheeting piles, should the pressure of the latter be greater than the former. To provide more securely against the effect of these pressures, intermediate string

pieces may be placed against the interior row of piles before the sheeting piles are driven; and the opposite sides of the dam on the interior may be buttressed by cross pieces reaching across the top string pieces, and by horizontal beams placed at intermediate points between the top and bottom of the dam.

The main inconvenience met with in coffer-dams arises from the difficulty of preventing leakage under the dam. In all cases the piles must be driven into a firm stratum, and the sheeting piles should equally have a firm footing in a tenacious compact sub-stratum. When an excavation is requisite on the interior, to uncover the subsoil on which the bed of the foundation is to be laid, the sheeting piles should be driven at least as deep as this point, and somewhat below it if the resistance offered to the driving does not prevent it.

The puddling should be formed of a mixture of tenacious clay and sand, as this mixture settles better than pure clay alone. Before placing the puddling, all the soft mud and loose soil between the sheeting piles should be carefully extracted; the puddling should be placed in and compressed in layers, care being taken to agitate the water as little as practicable.

With requisite care coffer-dams may be used for foundations in any depth of water, provided a water-tight bottoming can be found for the puddling. Sandy bottoms offer the greatest difficulty in this respect, and when the depth of water is over 5 feet, extraordinary precautions are requisite to prevent leakage under the puddling.

When the depth of water is over 10 feet, particularly where the bottom is composed of several feet of soft mud, or of loose soil, below which it will be necessary to excavate to obtain a firm stratum for the bed of the foundation, additional precautions will be requisite to give sufficient support to the interior sheeting piles against the pressure of the puddling, to provide against leakage under the puddling, and to strengthen the dam against the pressure of the exterior water, when the interior space is pumped dry and excavated. The best means for these ends, when the locality will admit of their application, is to form the exterior of the dam, as has already been described, by using piles and sheeting piles, giving to the latter additional points of support, by intermediate string pieces between the one at top and the bottom of the water; and to form a strong framing of timber for a support to the interior sheeting piles, giving to it the dimensions of the area to be enclosed. The frame-work (Fig. 23) may be composed of upright square beams, placed at suitable distances apart, depending on the strength required, upon which square string pieces are bolted at suitable distances from the top to the bottom, the bottom string resting on the surface of the mud. The string pieces

serving as supports for the sheeting piles, must be on the sides of the uprights towards the puddling, and their faces in the same

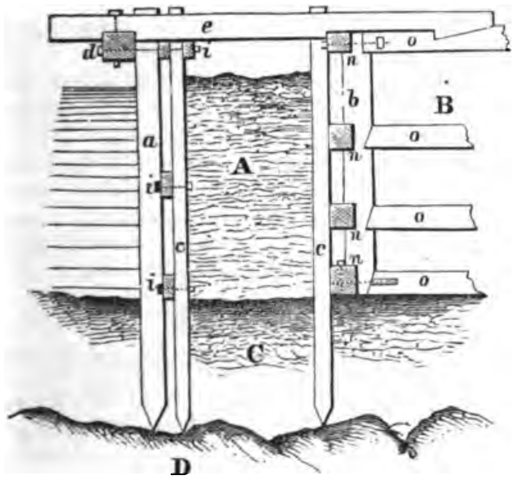


Fig. 23—Represents a section of the coffer-dam used for the Potomac aqueduct.
a, main exterior piles
b, strong square beams corresponding to *a* on which the wales *n*, *n* are notched and bolted.
c, sheeting piles.
d, top wale on main piles.
e, cross pieces.
i, guide and supporting string pieces for sheeting piles.
oo, horizontal shores buttressing opposite sides of dam.
A, puddling.
B, interior space.
C, mud, &c.
D, rock bottom.

vertical plane. Between each pair of opposite uprights, horizontal shores may be placed at the points opposite the position of the string pieces, to increase the resistance of the dam to the pressure of the water; the top shores extending entirely across the dam, and being notched on the top string pieces. The interior shores must be so arranged that they can be readily taken out as the masonry on the interior is built up, replacing them by other shores resting against the masonry itself.

397. When the bed of a river presents a rocky surface, or rock covered with but a few feet of mud, or loose soil, cases may occur in which it will be more economical and equally safe to lay a bed of beton without exhausting the water from the area to be built on; enclosing the area, before throwing in the beton, by a simple coffer work formed of a strong frame work of uprights and horizontal beams and sheeting piles. The frame work (Fig. 24) in this case is composed of uprights connected by string pieces in pairs; each pair is notched and bolted to the uprights, a sufficient interval being left between them for the insertion of the sheeting piles. To secure the frame work to the rock, it may be requisite to drill holes in the rock to receive the foot of each upright. The holes may be drilled by means of a long iron bar, termed a *jumper*, which is used for this purpose, or else the ordinary diving bell may be employed. This machine is very serviceable in all similar constructions where an examination of work under water is requisite, or in cases where it is necessary to lay

masonry under water. The frame work is put together on land, floated to its position, and settled upon the rock; the sheeting

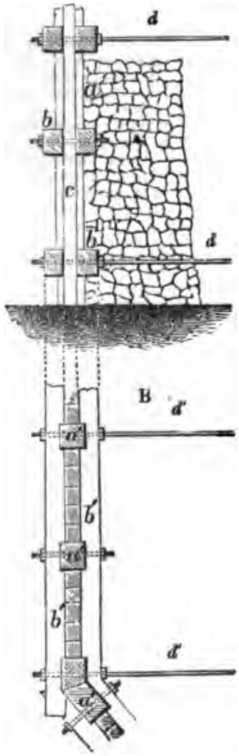


Fig. 24—Represents a coffer work for confining beton.
A, section of coffer work and beton.
B, plan of coffer work.
a, *a'*, square uprights connected by horizontal beams *b*, *b* bolted to them in pairs.
c, *c'*, sheeting piles inserted between the beams *b*, *b'* and the uprights *a*, *a'*.
d, *d'*, iron rods connecting opposite sides of coffer work

piles are then driven into close contact with the surface of the rock.

398. The convenience and economy resulting from the use of beton for the beds of structures raised in water, have led General Treussart to propose a plan for laying beds of this material, and then to take advantage of their strength and impermeability to construct a coffer-dam upon them, in order to carry on the superstructure with more care. To effect this, the space to be occupied by the bed (Fig. 25) is first enclosed by square piles, driven in juxtaposition and secured at top by a string piece. The mud and loose soil are then scooped from the enclosed area to the firm soil on which the bed of beton is to be laid. The bed of beton is next laid with the usual precautions, and while it is still soft a second row of square piles is driven into it, also in juxtaposition, and at a suitable distance from the first for the thickness of the dam

hese are also secured at top by a string piece. Cross pieces are

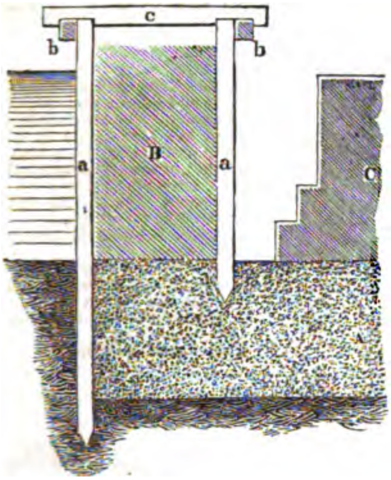


Fig. 25—Represents a section of General Treussart's dam.
A, bed of beton.
B, puddling of dam.
C, masonry of structure.
a, square piles.
b, wale pieces.
c, cross pieces.

notched upon the string pieces, to secure the rows of piles and form a scaffolding. An ordinary puddling is placed in between the rows of piles, and the interior space is pumped dry.

Should the soil under the bed of beton be permeable, the pressure of the water on the base of the bed may be sufficient to raise the bed and the dam upon it, when the water is taken from the interior space. A proper calculation will show whether this danger is to be apprehended, and should it be, a provisional weight must be placed on the dam, or the bed of beton, before exhausting the interior.

399. When the depth of water is great, or when, from the permeability of the soil at the bottom, it is difficult to prevent leakage, a coffer-dam may be a less economical method of laying foundations than the caisson. The *caisson* (Fig. 26) is a strong water-tight vessel having a bottom of solid heavy timber, and vertical sides so arranged that they can be readily detached from the bottom. The following is the usual arrangement of the caisson, it, like the coffer-dam, being subject to changes to suit it to the locality. The bottom of the caisson, serving as a platform for the foundation course of the masonry, is made level and of heavy timber laid in juxtaposition, the ends of the beams being confined by tenons and screw-bolts to longitudinal capping pieces of larger dimensions. The sides of the box are usually vertical. The sides are formed of upright pieces of scantling covered with thick plank, the seams being carefully calked to make the caisson water-tight. The lower ends of the uprights are inserted into shallow mortises made in the capping. The arrangement

for detaching the sides, is effected in the following manner Strong hooks of wrought iron are fixed to the bottom of the

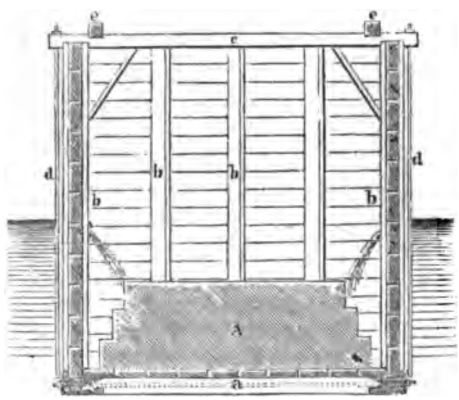


Fig. 26—Represents a cross section and interior end view of a caisson. The boards in this Fig. are represented as let into grooves in the vertical pieces, instead of being nailed to them on the exterior.
a, bottom beams let into grooves in the capping.
b, square uprights to sustain the boards.
c, cross pieces resting on *b*.
d, iron rods fitted to hooks at bottom and nuts at top.
e, longitudinal beams to stay the cross pieces *c*.
A, section of the masonry.

caisson at the sides of the capping piece, corresponding to the points where the uprights of the sides are inserted into this piece Pieces of strong scantling are laid across the top of the caisson, resting on the opposite uprights, upon which they are notched. These cross pieces project beyond the sides, and the projecting parts are perforated by an auger-hole, large enough to receive a bolt of two inches in diameter. The object of these cross pieces is twofold; the first is to buttress the sides of the caisson at top against the exterior pressure of the water; and the second is to serve as a point of support for a long bolt, or rod of iron, with an eye at the lower end, into which the hook on the capping piece is inserted, and a screw at top, to which a nut, or female screw is fitted, and which, resting on the cross pieces as a point of support, draws the bolt tight, and, in that way, attaches the sides and bottom of the caisson firmly together.

A bed is prepared to receive the bottom of the caisson, by levelling the soil on which the structure is to rest, if it be of a suitable character to receive directly the foundation; or by driving large piles through the upper compressible strata of the soil to the firm stratum beneath. The heads of the piles are sawed off on a level to receive the bottom of the caisson.

To settle the caisson on its bed, it is floated to and moored over it; and the masonry of the structure is commenced and carried up, until the weight grounds the caisson. The caisson should be so contrived, that it can be grounded, and afterwards raised, in case that the bed is found not to be accurately levelled To effect this, a small sliding gate should be placed in the side of the caisson, for the purpose of filling it with water at pleasure

By means of this gate, the caisson can be filled and grounded, and, by closing the gate and pumping out the water, it can be set afloat.

After the caisson is settled on its bed, and the masonry of the structure is raised above the surface of the water, the sides are detached, by first unscrewing the nuts and detaching the rods and then taking off the top cross pieces. By first filling the caisson with water, this operation of detaching the sides can be more easily performed.

400. To adjust the piles before they are driven, and to prevent them from spreading outward by the operation of driving, a strong grating of heavy timber, formed by notching cross and longitudinal pieces on each other, and fastening them firmly together, may be resorted to. This grating is arranged in a similar manner to a grillage; only the square compartments, between the cross and string pieces, are larger, so that they may enclose an area for 4 or 9 piles; and, instead of a single row of cross pieces, the grating is made with a double row, one at top, the other at the bottom, embracing the string pieces on which they are notched.

The grating may be fixed in its position at any depth under water, by a few provisional piles, to which it can be attached.

401. Where the area occupied by a structure is very considerable, and the depth of water great, the methods which have thus far been explained cannot be used. In such cases, a firm bed is made for the structure, by forming an artificial island of loose heavy blocks of stone, which are spread over the area, and receive a batter of from one perpendicular to one base, to one perpendicular and six base, according to the exposure of the bed to the effects of waves. This bed is raised several feet above the surface of the water, according to the nature of the structure, and the foundation is commenced upon it.

402. It is important to observe, that, where such heavy masses are laid upon an untried soil, the structure should not be commenced before the bed appears entirely to have settled; nor even then, if there be any danger of further settling taking place from the additional weight of the structure. Should any doubts arise on this point, the bed should be loaded with a provisional weight, somewhat greater than that of the contemplated structure, and this weight may be gradually removed, if composed of other materials than those required for the structure, as the work progresses.

403. To give perfect security to foundations in running water, the soil around the bed must be protected to some extent from the action of the current. The most ordinary method of effecting this, is by throwing in loose masses of broken stone of sufficient size to resist the force of the current. This method will

give all required security, where the soil is not of a shifting cha racter, like sand and gravel. To secure a soil of this last nature, it will, in some cases, be necessary to scoop out the bottom around the bed to a depth of from 3 to 6 feet, and to fill this excavated part with beton, the surface of which may be protected from the wear arising from the action of the pebbles carried over it by the current, by covering it with broad flat flagging stones.

404. When the bottom is composed of soft mud to any great depth, it may be protected by enclosing the area with sheeting piles, and then filling in the enclosed space with fragments of loose stone. If the mud is very soft, it would be advisable, in the first place, to cover the area with a grillage, or with a layer of brushwood laid compactly, to serve as a bed for the loose stone, and thus form a more stable and solid mass.

CONSTRUCTION OF MASONRY.

405. Under this head will be comprised whatever relates to the manner of determining the forms and dimensions of the most important elementary components of structures of masonry, together with the practical details of their construction.

406. *Foundation Courses.* As the object of the foundations is to give greater stability to the structure by diffusing its weight over a broad surface, their breadth, or *spread*, should be proportioned both to the weight of the structure and to the resistance offered by the subsoil. In a perfectly unyielding soil, like hard rock, there would be no increase of stability by augmenting the base of the structure beyond what would be strictly necessary to its stability in a lateral direction; whereas in a very compressible soil, like soft mud, it would be necessary to make the base of the foundation very broad, so that by diffusing the weight over a great surface, the subsoil may offer sufficient resistance, and any unequal settling be obviated.

407. The thickness of the foundation course will depend on the spread; the base is made broader than the top from motives of economy. This diminution of the volume (Fig. 27) is made

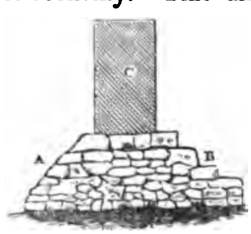


Fig. 27—Section of foundation courses and superstructure.
A, batter.
B, offsets.
C, superstructure.

either in steps, termed *offsets*, or else by giving a uniform batter from the base to the top. The latter method is now generally

used; it presents equal stability with the former with a smaller volume.

When the foundation has to resist only a vertical pressure, an equal batter is given to it on each side; but if it has to resist also a lateral effort, the spread should be greater on the side opposed to this effort, in order to resist its tendency, which would be to cause a yielding on that side.

408. The bottom course of the foundations is usually formed of the largest sized blocks, roughly dressed off with the hammer; but if the bed is compressible, or the surfaces of the blocks are winding, it is preferable to use blocks of a small size for the bottom course; because these small blocks can be firmly settled, by means of a heavy beetle, into close contact with the bed, which cannot be done with large sized blocks, particularly if their under surface is not perfectly plane. The next course above the bottom one should be of large blocks, to bind in a firm manner the smaller blocks of the bottom course, and to diffuse the weight more uniformly over them.

409. When a foundation for a structure rests on isolated supports, like the pillars, or columns of an edifice, an *inverted* or *counter-arch*, (Fig. 28,) should connect the top course of the foundation under the base of each isolated support, so that the pressure on any two adjacent ones may be distributed over the bed of the foundation in the interval between them. This precaution is obviously necessary only in compressible soils. In incompressible soils it would be alone requisite to carry up the courses immediately below each support with great care, to present a stable bed for the base of the support.

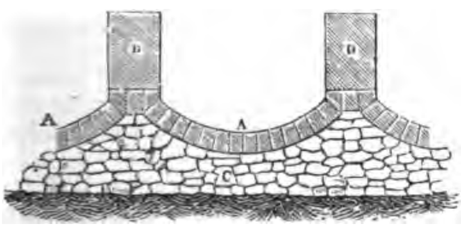


Fig. 28—Section of vertical supports on reversed arches.
A, reversed arch.
B, vertical supports.
C, bed of stone.

The reversed arch is also used to give greater breadth to the foundations of a wall with counterforts, and in cases where an upward pressure from water, or a semi-fluid soil requires to be counteracted. In the former case the reversed arches are turned under the counterforts; in the latter they form the points of support of the walls of the structure.

410. The angles of the foundations should be formed of the most massive blocks. The courses should be carried up uni

formly throughout the foundation, to prevent unequal settling in the mass.

The stones of the top course of the foundation should be sufficiently large to allow the course of the superstructure next above to rest on the exterior stones of the top course.

411. Hydraulic mortar should be used for the foundations and the upper courses of the structure should not be commenced until the mortar has partially set throughout the entire foundation.

412. *Component parts of Structures of Masonry* These may be divided into several classes, according to the efforts they sustain; their forms and dimensions depending on these efforts.

1st. Those which sustain only their own weight, and are not liable to any cross strain upon the blocks of which they are formed, as the walls of enclosures.

2d. Those which, besides their own weight, sustain a vertical pressure arising from a weight borne by them, as the walls of edifices, columns, the piers of arches, &c.

3d. Those which sustain lateral pressures, and cross strain upon the blocks, arising from the action of earth, water, frames or arches.

4th. Those which sustain a vertical upward, or downward pressure, and a cross strain, as areas, lintels, &c.

5th. Those which transfer the pressure they directly receive to lateral points of support, as arches.

413. *Walls of Enclosures.* Walls for these purposes may be built of brick, rubble, or dry stone.

Brick walls are usually built vertically upon the two faces; their thickness cannot be less than that of one brick. A wall of one brick and a half thick will serve for any length, provided the height be not over 15 or 20 feet.

Rubble stone walls should never receive a thickness less than 18 inches when the two faces are vertical. Rondelet, in his work *l'Art de Bâtir*, lays down a rule that the mean thickness of both rubble and brick walls should be $\frac{1}{18}$ of their height.

Dry stone walls should not receive a less thickness than two feet. When their height exceeds 12 feet, their mean thickness should be $\frac{1}{6}$ of the height.

Stone walls are usually built with sloping faces. The batter should not be greater, when the stones are cemented with mortar, than one base to six perpendicular, in order that the rain may run rapidly from the surface, and that the wall be not too much exposed to decay from the germination of seeds which may lodge in the joints.

The batter is arranged either by building the wall in offsets from top to bottom, or by a uniform surface. In either case, the

thickness of the wall at top should not be less than from 8 to 12 inches.

When a wall is built with an equal batter on each face, and the thickness at the top and the mean thickness are fixed, *the base of the wall*, or its thickness at the bottom, *will be found by subtracting the thickness at top from twice the mean thickness.* This rule evidently makes the batter of the wall depend upon the two preceding dimensions.

The mean thickness of long walls may be advantageously diminished by placing counterforts, or buttresses, upon each face at equal distances along the line of the wall. These are spurs of masonry projecting some length from the wall, and are firmly connected with it by a suitable bond. The horizontal section of the counterforts may be rectangular; their height should be the same as that of the wall.

In rubble wall the counterforts may be made of hammered, or cut stone. In addition to this means of strengthening walls, horizontal courses, or chains of dressed stone may be advantageously used from distance to distance, from the bottom of the wall upward.

414. *Vertical Supports.* These consist of walls, columns, or pillars, according to circumstances. The dimensions of the courses of masonry which compose the supports should be regulated by the weight borne. If, as in the walls of edifices, the resultant of the efforts sustained by the wall should not be vertical, it must not intersect the base of the wall so near the outer edge, that the stone forming the lowest course would be in danger of being crushed.

In broad enclosed spaces covered at top, the dimensions of the wall may be calculated as in the case of ordinary enclosures, and the dimensions thus obtained be increased in proportion to the weight to be borne.

Cross walls between the exterior walls, as the partition walls of edifices, should be regarded as counterforts which strengthen the main walls.

415. *Areas.* The term *area* is applied to a mass of masonry, usually of a uniform thickness, laid over the ground enclosed by the foundations of walls. It seldom happens that areas have an upward pressure to sustain. Whenever this occurs, as in the case of the bottoms of cellars in communication with a head of water which causes an upward pressure, the thickness and arrangement of the area should be regulated to resist this pressure. When the pressure is considerable, an area of uniform thickness may not be sufficiently strong to ensure safety; in this case an *inverted arch* must be used.

416. *Retaining*, or *Sustaining Walls.* These terms are ap-

plied to walls which sustain a lateral pressure from an embankment, or a head of water.

417. Retaining walls may yield by sliding either along the base of the foundation courses, or along one of the horizontal joints, or by rotation about the exterior edge of some one of the horizontal joints.

418. The determination of the form and dimensions of a retaining wall for an embankment of earth is a problem of considerable intricacy, and the mathematical solutions which have been given of it have generally been confined to particular cases, for which approximate results alone have been obtained; these, however, present sufficient accuracy for all practical purposes within the limits to which the solutions are applicable. Among the many solutions of this problem, those given by M. Poncelet of the Corps of French Military Engineers, in a Memoir on this subject, published in the *Mémorial de l'Officier du Génie*, No. 10, present a degree of research and completeness which peculiarly characterize all the writings of this gentleman, and have given to his productions a claim to the fullest confidence of practical men.

The following formula, applicable to cases of rotation about the exterior edge of the lowest horizontal joint, are taken from the memoir above cited.

Calling H, the height BC (Fig. 29) of a wall of uniform thickness, the face and back being vertical.

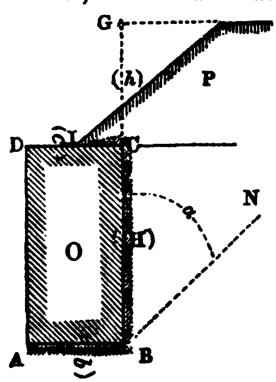


Fig. 29—Represents a section O of a retaining wall with the face and back vertical. P, section of the embankment above the wall.

h, the mean height CG of the embankment, retained by the wall, above the top of the wall.

c, the *berm* DI, or distance between the foot of the embankment and the outer edge of the top of the wall.

a, the angle between the line of the natural slope BN of the earth of the embankment and the vertical BG.

f = cot. *a*, the co-efficient of friction of the earth of the embankment.

w, the weight of a cubic foot of the earth.
w', the weight of a cubic foot of the masonry of the wall.
b, the base AB, or thickness of the wall at bottom.

Then,

$$b=0.74 \tan. \tfrac{1}{2}\alpha \sqrt{\frac{w}{w'}}(h+1.126\text{H})+0.0488h-0.56c \tan. \alpha \left(\frac{h}{\text{H}}-0.6\frac{w}{w'}\right)\left(\frac{h}{\text{H}}-0.25\right).$$

The above formula gives the value of the base of a wall with vertical faces, within a near degree of approximation to the true result, only when the values of the quantities which enter into it are confined within certain limits. These limits are as follows: for h, between 0 and H; c, between 0 and $\frac{1}{2}$H; f, between 0.6 and 1.4, which correspond to values of α of 70° and 35°, being in the one case the angle which the line of the natural slope of very fine dry sand assumes, and in the other of heavy clayey earth: and for w, between w', and $\frac{3}{4}w'$. Besides these limits, the formula also rests on the assumption that the excess of stability of the wall over that of a strict equilibrium is represented by 0.912; or, in other words, that the moment of the pressure against the wall is taken 0.912 greater than the moment of strict equilibrium between it and the wall. This excess of stability given to the wall supposes an excess of resistance above the pressure against it equal to what obtains in the retaining walls of Vauban, for fortifications which have now stood the test of more than a century with security.

419. Having by the preceding formula calculated the value of b for a vertical wall, the base b' of another wall, presenting equal stability, but having a batter on the face, the back being vertical,

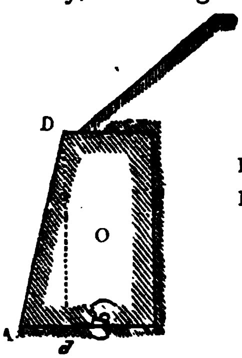


Fig. 30—Represents a section O of a retaining wall with a sloping face AD.
P, section of the embankment.

which is the usual form of the cross section of retaining walls, can be calculated from the following notation and formula.

Calling (Fig. 30) b' the base of the sloping wall.

$n = \frac{Ad}{Dd'}$, the batter, or ratio of the base of the slope to the perpendicular, or height of the wall.

Then,

$$b' = b + \tfrac{1}{18}nH.$$

420. With regard to sliding either on the base of the foundation courses, or on the bed of any of the horizontal joints of the wall, M. Poncelet shows, in the memoir cited, by a comparison of the results obtained from calculations made under the suppositions both of rotation and sliding, that no danger need be apprehended from the latter, when the dimensions are calculated to conform to the former, so long as the limits of h are taken between 0 and 4H; particularly if the precaution be taken to allow the mortar of the masonry to set firmly before forming the embankment behind the wall.

421. *Form of Section of Retaining Walls.* Retaining walls have been built with a variety of forms of cross section. The more usual form of cross section is that in which the back of the wall is built vertically, and the face with a batter varying between one base to six perpendicular, and one base to twenty-four perpendicular. The former limit having been adopted, for the reasons already assigned, to secure the joints from the effects of weather; and the latter because a wall having a face more nearly vertical, is liable in time to yield to the effects of the pressure, and lean forward.

422. The most advantageous form of cross section for economy of masonry is the one (Fig. 31) termed a *leaning* retaining

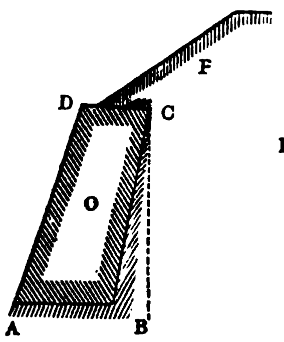


Fig. 31—Represents a section O of a leaning retaining wall with a sloping face AD and the back BC counter-sloped.

wall. The counter slope, or reversed batter of the back of the wall, should not be less than six perpendicular to one base. In this case strength requires that the perpendicular let fall from the centre of gravity of the section upon the base, should fall so far within the inner edge of the base, that the stone of the bottom

course of the foundation may present sufficient surface to bear the pressure upon it.

423. Walls with a curved batter (Fig. 32) both upon the face and back, have been used in England, by some engineers, for quays. They present no peculiar advantages in strength over

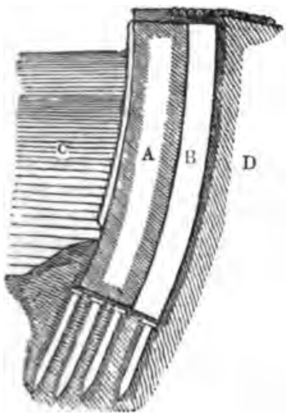


Fig. 32—Represents a section A of a wall with a curved face and back, and an elevation B of the counterforts.
C, water.
D, embankment behind the wall.
a, fender beams of timber

walls with plane faces and backs, and require particular care in arranging the bond, and fitting the stones or bricks of the face.

424. *Measures for increasing the Strength of Retaining Walls.* These consist in the addition of counterforts, in the use of relieving arches, and in the modes of forming the embankment.

425. Counterforts give additional strength to a retaining wall in several ways. By dividing the whole line of the wall into shorter lengths between each pair of counterforts, they prevent the horizontal courses of the wall from yielding to the pressure of the earth, and bulging outward between the extremities of the walls; by receiving the pressure of the earth on the back of the counterfort, instead of on the corresponding portion of the back of the wall, its effect in producing rotation about the exterior foot of the wall is diminished; the sides of the counterforts acting as abutments to the mass of earth between them may, in the case of sand, or like soil, cause the portion of the wall between the counterforts to be relieved from a part of the pressure of the earth behind it, owing to the manner in which the particles of sand become buttressed against each other when confined laterally, and offer a resistance to pressure.

426. The horizontal section of counterforts may be either rectangular, or trapezoidal. When placed against the back of a wall, the rectangular form offers the greater stability in the case of rotation, and is more economical in construction; the trape

zoidal form gives a broader and therefore a firmer connection between the wall and counterfort than the rectangular, a point of some consideration where, from the character of the materials, the strength of this connection must mainly depend upon the strength of the mortar used for the masonry.

427 Counterforts have been chiefly used by military engineers for the retaining walls of fortifications, termed *revêtements*. In regulating their form and dimensions, the practice of Vauban has been generally followed, which is to make the horizontal section of the counterfort trapezoidal, making the height of the trapezoid *ef*, (Fig. 33,) which corresponds to the length of the counterfort, *two tenths of the height of the wall added to two feet*, the base of the trapezoid *ab* corresponding to the junction of the counterfort and back of the wall, *one tenth of the height added to two feet*, and the side *cd* which corresponds to the back of the counterfort equal to two thirds of the base *ab*. The counterforts are placed

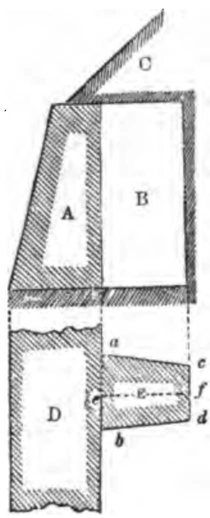


Fig. 33—Represents a section A, and plan D of a wall, and an elevation B, and plan E of a trapezoidal counterfort.

from 15 to 18 feet from centre to centre along the back of the wall, according to the strength required.

428. In adding counterforts to walls, the practice has generally been to regard them only as giving additional stability to the wall, and not as a means of diminishing its volume of masonry of which the addition of the counterforts ought to admit. Considered in this last point of view, the problem for determining both the suitable dimensions of the counterforts and the thickness of the corresponding wall, is one of very considerable mathematical difficulty, whose solution must repose upon assumptions made as

to the manner in which the portions of the wall between the counterforts would be likely to yield to the pressure upon them, the support which they receive from the two counterforts at their extremities, and the stability which the counterforts add to the entire system in preventing rotation.

429. *Relieving Arches* are so termed from their preventing a portion of the embankment from resting against the back of the wall, and thus relieving it from a part of the pressure. They consist (Fig. 34) of one or more tiers of brick arches built upon counterforts, which act as the piers of the arches.

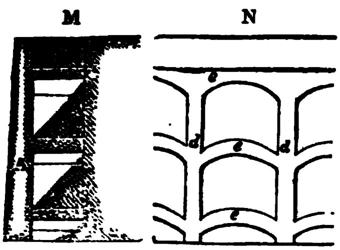


Fig. 34—Represents a section M and an elevation N of a wall and relieving arches in three tiers.
A, section of the wall.
c, c, c, sections of the arches through their crowns.
d, d, interior elevations of counterforts serving as piers of the arches.
e, e, interior end elevations of arches.

In arranging a combination of relieving arches and their piers, the latter, like ordinary counterforts, are placed about 18 feet apart between their centre lines; their length should be so regulated that the earth behind them resting on the arches, and falling under them with the natural slope, shall not reach the wall between the arch and the foot of the back of the wall below the arch. The thickness of the arches, as well as that of the counterforts, will depend upon the weight which the arches sustain. The dimensions of the wall will be regulated by the decreased pressure against it caused by the action of the arches, and the point at which this pressure acts.

430. Whenever it becomes necessary to form the embankment before the mortar of the retaining wall has had time to set firmly, various expedients may be employed to relieve the wall from the pressure which the embankment, if formed of loose earth, would throw upon it. The portion of the embankment next to the wall may be of a compact binding earth placed in layers inclining downward from the back of the wall, and well rammed; or of a stiff mortar made either of clay, or sand, with about $\frac{1}{18}$th in bulk of lime. Instead of bringing the embankment directly against the back of the wall, dry stone, or fascines may be laid in to a suitable depth back from the wall for the same purpose. The precaution, however, of allowing the mortar to set firmly before forming the embankment, should never be omitted except in cases of extreme urgency, and then the bond of the masonry should be

arranged with peculiar care, to prevent disjunction along any of the horizontal joints.

431. Walls built to sustain a pressure of water should be regulated in form and dimensions like the retaining walls of embankments. The problem in this case is one of less difficulty than in the other, from the greater simplicity of the mathematical formula for the pressure of water. The buoyant effort of the water must be taken into account in this calculation, whenever the masonry is so placed as to be partially immersed in the water.

432. Heavy walls, and even those of ordinary dimensions, when exposed to moisture, should be laid in hydraulic mortar. Grout has been tried in laying heavy rubble walls, but with decided want of success, the successive drenchings of the stone causing the sand to separate from the lime, leaving when dry a weak porous mortar. When the stone is laid in full mortar, grout may be used with advantage over each course, to fill any voids left in the mass.

433. Beton has frequently been used as a filling between the back and facing of water-tight walls; it presents no advantage over walls of cut, or rubble stone laid in hydraulic mortar, and causes unequal settling in the parts, unless great care is taken in the construction.

434. When a weight, arising from a mass of masonry or earth, rests upon two or more isolated supports, that portion of it which is distributed over the space, or *bearing* between any two of the supports, may be borne by a block of stone, termed a *lintel*, laid horizontally upon the supports, by a combination of blocks termed a *plate-bande*, so arranged as to resist, without disjunction, the pressure upon them; or by an arch.

435. *Lintel.* Owing to the slight resistance of stone to a cross strain, and to shocks, lintels of ordinary dimensions cannot be used alone with safety, for bearings over six feet. For wider bearings, a slight brick arch is thrown across the bearing above the lintel, and thus relieves it from the pressure of the parts above.

436. *Plate-bande.* The plate-bande is a combination of blocks cut in the form of truncated wedges. From the form of the blocks, the pressure thrown upon them causes a lateral pressure which must be sustained either by the supports, or by some other arrangement, (Fig. 35.)

The plate-bande should be used only for narrow bearings, as the upper edges of the blocks at the acute angles are liable to splinter from the pressure. If the bearing exceeds 10 feet, the plate-bande should be relieved from the pressure by a brick arch above it. Additional means of strengthening the plate-bande are sometimes used by forming a broken joint between the blocks, or

by a projection made on the face of one block to fit into a corresponding indent in the adjacent one, or by connecting the blocks with iron bolts.



Fig. 35—Represents a cross section of a plate-bande, showing the manner in which the voussoirs A, A and B are cut and connected by metal cramps. *ab*, tie of wrought iron for the plate-bande fastened to the bolts *cd*, let into the piers of the plate bande.

When, from any cause, the supports cannot be made sufficiently strong to resist the lateral pressure of the plate-bande, the extreme blocks must be united by an iron bar, termed a *tie*, suitably arranged to keep the blocks from yielding.

437. *Arches.* The arch is a combination of wedge-shaped blocks, termed *arch stones*, or *voussoirs*, truncatéd towards the angle of the wedges by a curved surface which is usually normal to the surfaces of the joints between the blocks. This inferior surface of the arch is termed the *intrados*, or *soffit*. The upper, or outer surface of the arch is termed the *extrados*, or *back*, (Fig. 36.)

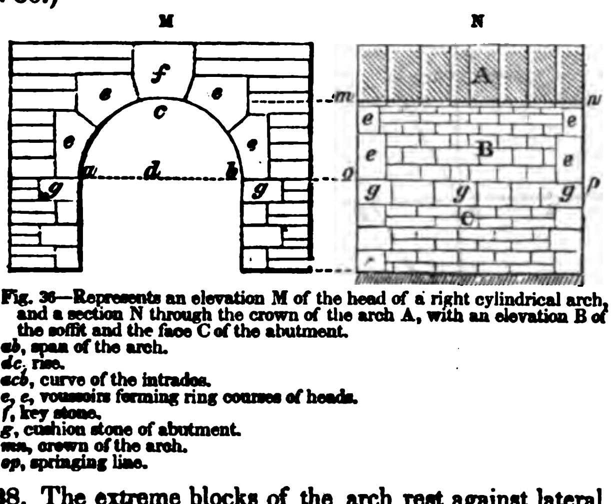


Fig. 36—Represents an elevation M of the head of a right cylindrical arch, and a section N through the crown of the arch A, with an elevation B of the soffit and the face C of the abutment.
***ab*, span of the arch.**
***dc*, rise.**
***acb*, curve of the intrados.**
***e, e*, voussoirs forming ring courses of heads.**
***f*, key stone.**
***g*, cushion stone of abutment.**
***mn*, crown of the arch.**
***op*, springing line.**

438. The extreme blocks of the arch rest against lateral supports, termed *abutments*, which sustain both the vertical pressure arising from the weight of the arch stones, and the weight of whatever lies upon them; also the lateral pressure caused by the action of the arch.

439. In a *range*, or series of arches placed side by side, the

extreme supports are termed the abutments, the intermediate supports which sustain the intermediate arches and the halves of the two extreme ones are termed *piers*. When the size of the arches is the same, and their springing lines are in the same horizontal plane, the piers receive no other pressure but that arising from the weight of the arches.

440. Arches are classified, from the form of the soffit, into *cylindrical*, *conical*, *conoidal*, *warped annular*, *groined*, *cloistered*, and *domes*. They are also termed *right*, *oblique*, or *askew*, and *rampant*, from their direction with respect to a vertical, or horizontal plane.

441. *Cylindrical Arch*. This is the most usual and the simplest form of arch. The soffit consists of a portion of a cylindrical surface. When the section of the cylinder perpendicular to the axis of the arch, termed a *right section*, cuts from the surface a semi-circle, the arch is termed a *full centre* arch; when the section is an arc less than a semi-circle, it is termed a *segment arch*; when the section gives a semi-ellipse, it is termed an *elliptical arch*; when the section gives a curve resembling a semi-ellipse, formed of arcs of circles tangent to each other, the arch is termed an *oval*, (Fig. 37,) or *basket handle*, and is called

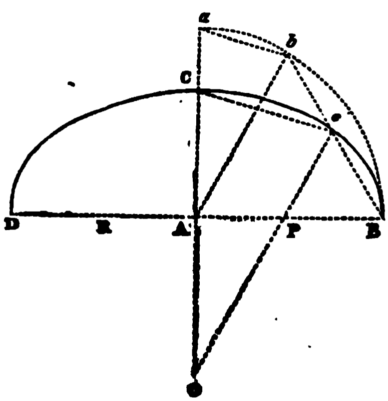


Fig. 37—Represents an oval curve of three centres, the arcs of which are each 60°.
DB, span of the curve.
AC, rise.
P, O, and R, centres of the arcs of 60°.

a curve of three, five, &c. *centres*, according to the number of arcs, which must be odd to obtain a curve symmetrical with respect to the vertical line bisecting it; when the section is that of two arcs of circles intersecting at the middle point of the curve, it is termed a *pointed*, or an *obtuse* or *surbased arch*, (Figs. 38 and 39,) according as the angle between the arcs at their intersection is acute, or obtuse.

A cylindrical arch is denominated a *right arch* when it is terminated by two planes, termed the *heads* of the arch, perpendicu

lar to the axis of the arch; *oblique*, or *askew*, when the heads are oblique to the axis; and *rampant* when the axis of the arch is oblique to the horizontal plane.

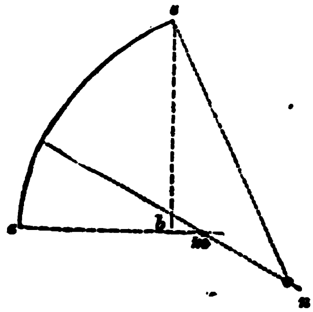


Fig. 38—Represents the half of a pointed curve of four centres.
ab, half span.
bc, rise.
m and *n*, centres of the half curve *ac*.

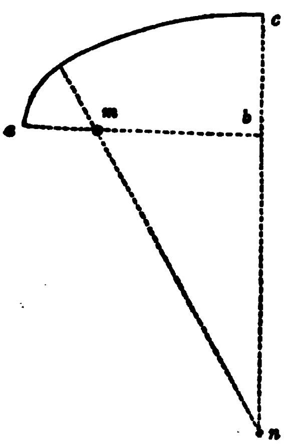


Fig. 39—Represents the half of an obtuse or surbased curve of four centres.
ab, half span.
bc, rise.
m and *n*, centres of the half curve *ac*.

442. The chord of the curve of right section (see Fig. 36) is termed the *span* of the arch, its versed sine the *rise* of the arch. When the heads of the arch are oblique to the axis, the chord of the oblique section made by the plane of the heads is termed the *span* of the *askew* section. The lines of the soffit corresponding to the extremities of the span are termed the *springing lines* of the arch; the top portion, or line of the soffit, is termed the *crown*. The top stone of the crown the *key stone*. The line drawn through the middle point of the span at the extremities of the arch, is termed the *axis* of the arch.*

443. The form of right section will depend upon the purposes which the arch is to serve, the locality, and the style of architecture employed. When the rise is less than half the span, the arch is weaker than in either the full centre, or where the rise is

* *See Note C, Appendix.*

greater than half the span. The methods of describing the various curves of right section will be explained in the Appendix.

444. The same general principle is followed in arranging the joints and bond of the masonry of arches, as in other structures of cut stone. The surfaces of the joints should be normal to the surface of the soffit, and the surfaces of any two systems of joints should be normal to each other at their lines of intersection. These conditions, with respect to the joints, will be satisfied by tracing upon the soffit its lines of least and greatest curvature, and taking the edges of one series of joints to correspond with one of these systems of lines, and the edges of the other series with the other system, the surfaces of the joints being formed by the surfaces normal to the soffit along the respective lines in question. Whenever the surface of the soffit belongs to any of the families of geometrical surfaces, the joints will be thus either plane, or developable surfaces. In the cylindrical arch, for example, the edges of one series of joints will correspond to the elements of the cylindrical surface, while those of the other will correspond to the curves of right section, the former answering to the line of least, and the latter of greatest curvature. The surfaces of the joints will all be plane surfaces, and, being normal to the soffit along the lines in question, will be normal also to each other.

445. In full centre and segment arches, the voussoirs are usually made of the same breadth, estimated along the curve of right section. The planes of the joints of each course of voussoirs between the heads of the arch are made continuous, (see Fig. 36,) each of these courses being termed a *string* course, and their joints *coursing joints*. The planes of the joints along the curves of right section are not continuous, but break joints; the stones which correspond to two consecutive series of these joints being termed a *ring course*, and its joints *heading joints*. By this combination of the ring and string courses, the fitting of the blocks, the settling of the courses, and the bond are arranged in the best manner.

446. In the other forms of right section of cylindrical arches, it may not, in many cases, be practicable to give the voussoirs the same breadth, owing to the variable curvature of the right section; but the same arrangement is followed for the ring and string courses.

447. In oblique cylindrical arches, when the obliquity is but slight, no change will be required in the arrangement of the courses and joints; but when the angle between the heads and the axis is considerably less than a right angle, the ring courses at the extremities of the arch would have what is termed a *false bearing*, that is, the pressure upon their coursing joints would

not be transmitted in the direction of the pressure to the fixed lateral supports, and therefore these portions of the arch would be insecure. To obviate these defects, as well as the unequal bearing upon the lateral supports in such case, arrangements of the coursing and heading joints have been devised, by which a better bond is obtained, and the total pressure from the voussoirs thrown upon the abutments.

One method for this purpose has been mostly used in England; and consists in placing the edges of the heading and coursing joints along spiral lines of the cylindrical soffit which intersect each other at right angles. The *directing* spirals for the heading joints (Fig. 40) being taken parallel to the one which is drawn con

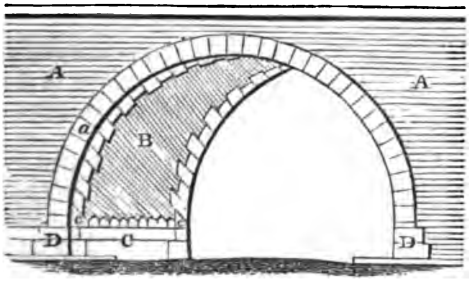


Fig. 40—Represents an elevation A of the head and of a part of the soffit B of an oblique cylindrical arch with spiral joints.
a, voussoirs of cut stone.
c, c, bottom course of stone voussoirs cut to receive the brick courses.
C, face of the abutment.
D, ends of the abutments

necting the extreme points of the askew curve of the head; those for the coursing being traced perpendicular to the former. The joints being normal to the soffit along the spirals, will be helicoidal surfaces. This method palliates only to some extent the weakness of the bond in the courses near the heads, and giving a considerable dip to the coursing joints at the extremities of the abutments which make an acute angle with their faces, it presents here also a weak point. It possesses an important advantage, however, in permitting the soffit ends of the string courses to be of equal breadth throughout, and therefore allows the method to be adapted as well to brick as cut stone. To bring the coursing joints to correspond exactly with the divisions of the ring courses of the heads, it may be necessary, in some cases, to shift the spirals of the coursing joints slightly, in making the drawings for the arch. The end blocks of the string courses which rest upon the abutment, or else the top course of the abutment, must be suitably cut to correspond to the direction of the heading joints and that of the horizontal courses of the abutment.

448. A second method, in use among the French engineers, consists in making the heading joints plane surfaces and parallel to the heads of the arch, and in taking for the edges of the coursing joints (Fig. 41) the *trajectories* traced on the soffit perpendicular to the edges of the heading joints. The surfaces of the coursing

joints are made normal to the soffit. By this plan some of the defects of the former are remedied, but it has the disadvantage

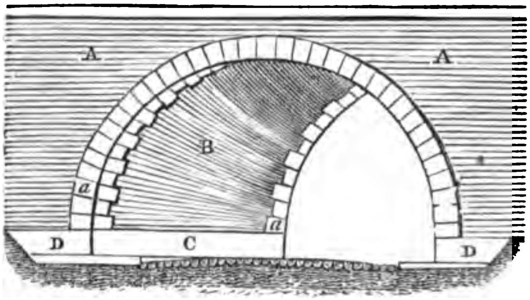


Fig. 41—Represents an elevation of the head and a portion of the soffit of an oblique cylindrical arch, with the edges of the coursing joints forming trajectories at right angles to the edges of heading joints parallel to the curves of the heads of the arch. The letters refer to same parts as in Fig. 40.

of giving an unequal breadth to the soffit ends of the voussoirs, and therefore is inapplicable to brick arches. The curves of the trajectories and the coursing joints are of more difficult construction than in the first method.

449. Cylindrical, groined, and cloistered arches are formed by the intersections of two or more cylindrical arches. The span of the arches may be different, but the rise is the same in each. The axes of the cylinders will be in the same plane, and they may intersect under any angle.

The groined arch (Fig. 42) is formed by removing those por-

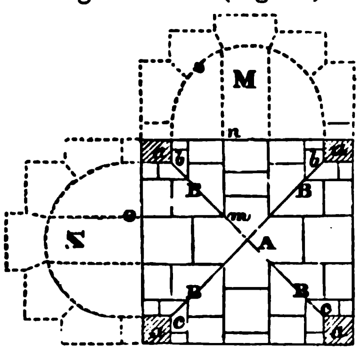


Fig. 42—Represents the plan of the soffit and the right sections M and N of the cylinders forming a groined arch.
aa, pillars supporting the arch.
bc, groins of the soffit.
om, *mn*, edges of coursing joints.
A, key stone of the two arches formed of one block.
B, B, groin stones of one block below the key stone forming a part of each arch

tions of each cylinder which lie under the other and between their common curves of intersection; thus forming a projecting, or salient edge on the soffit along these curves.

The cloistered arch (Fig. 43) is formed by removing those portions of each cylinder which are above the other and exterior to their common intersection, forming thus re-entering angles along the same lines.

450. The planes of the joints in both of these arches are placed in the same manner as in the simple cylindrical arch. The inner

edges of the correspond'ng course of voussoirs in each arch are placed in the same plane parallel to that of the axes of the cylin-

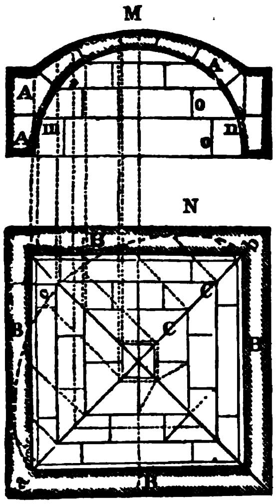


Fig. 43—Represents a section M of the voussoirs and an elevation of the soffit of a cloistered arch with a plan N of the soffit.
A, A, voussoirs.
mn, edge of coursing joint.
o, *o*, edges of heading joints
B, B, abutments of the arches.
acb, curve of the groin.
C, C, groin stones of one block.

ders. The portions of the soffit in each cylinder, corresponding to each course of voussoirs, which form either the groin in the one case, or the re-entering angle in the other, are cut from a single stone, to present no joint along the common intersection of the arches, and to give them a firmer bond.

451. Conical arches are of rare application. When used, the same general principles with respect to the joints and bond apply to them. The surfaces of one set of joints will be planes passed through the elements of the cone and normal to the soffit; the other will be conical, or other surfaces, likewise normal to the soffit and passing through the curves of least curvature.

452. When the spans at the two ends of an arch are unequal, but the rise is the same, then the soffit of the arch is made of a conoidal surface. The curves of right section at the two ends may be of any figure, but are usually taken from some variety of the elliptical, or oval curves. The soffit is formed by moving a line upon the two curves, and parallel to the plane containing their spans.

The conoidal arch belongs to the class with warped soffits. A variety of warped surfaces may be used for soffits according to circumstances; the joints and the bond depending on the generation of the surface.

453. In arranging the joints in conoidal arches, the heading joints are contained in planes perpendicular to the axis of the arch. The coursing joints are also formed of plane surfaces, so

arranged that the portion of the joint corresponding to each block is formed by a plane normal to the conoid at the middle point of the lower edge of the block. In this way the joints of the string course will not be formed of continuous surfaces. To make them so, it would be necessary to give them the form of warped surfaces, which present more difficulty in their mechanical execution, and not sufficient advantages over the method just explained to compensate for having them continuous.

454. The annular arch is formed by revolving the plane of a semi-circle, or semi-oval, or other curve, about a line drawn without the figure and parallel to the rise of the arch, (Fig. 44.) One

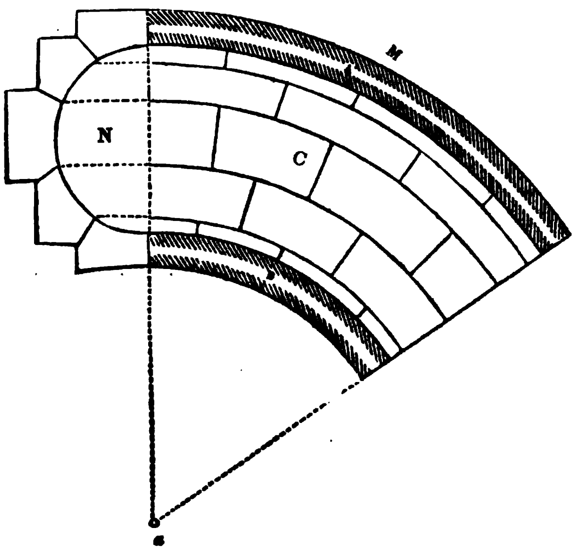


Fig. 44—Represents a plan M of the abutments A and B, and the soffit C of an annular arch. N, right section of the arch. a, position of vertical axis around which the section N is revolved.

series of joints in this arch will be formed by conical surfaces passing through the inner edges of the stones which correspond to the string courses; and the other series will be planes passed through the axis about which the semi-circle is revolved. This last series should break joints with each other.

455. The soffit of a dome is usually formed by revolving the quadrant of one of the usual curves of cylindrical arches around the rise of the curve; or else by revolving the semi-curve about the line of the span, and taking the half of the surface thus generated for the soffit of the dome. In the first of these cases the horizontal section of the dome at the springing line will be a circle; in the second the entire curve of the semi-curve by which the soffit is generated. The plan of domes may also be of regular polygonal figures, in which case the soffit will be a polygonal-

cloistered arch formed of equal sections of cylinders, (Fig. 45.) The joints and the bond are determined in the same manner as in other arches.

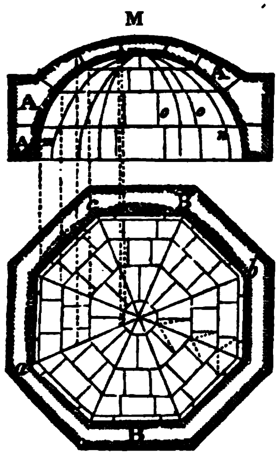


Fig. 45—Represents a section M of the voussoirs and an elevation of the soffit, with a plan N of the soffit of an octagonal-cloistered dome.
The letters refer to the same parts as in Fig. 43.

456. The voussoirs which form the ring course of the heads, in ordinary cylindrical arches, are usually terminated by plane surfaces at top and on the sides, for the purpose of connecting them with the horizontal courses of the head which lie above and on each side of the arch, (Figs. 46 and 47.) This connection

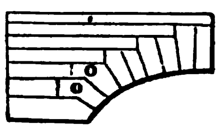


Fig. 46—Represents a manner of connecting the voussoirs and horizontal courses in an oval arch.
o, *o*, are examples of voussoirs with elbow joints.

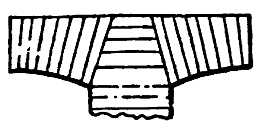


Fig. 47—Represents a mode of arranging the voussoirs and horizontal courses in flat segment arches

may be arranged in a variety of ways. The two points to be kept in view are, to form a good bond between the voussoirs and horizontal courses, and to give a pleasing architectural effect by the arrangement. This connection should always give a symmetrical appearance to the halves of the structure on each side of the crown. To effect these several objects it may be necessary, in cases of oval arches, to make the breadth of the voussoirs unequal, diminishing usually those near the springing lines.

457. In small arches the voussoirs near the springing line are so cut as to form a part also of the horizontal course, (see Fig. 46,) forming what is termed an *elbow joint*. This plan is objec

tionable, both because there is a waste of material in forming a joint of this kind, and the stone is liable to crack when the arch settles.

458. The forms and dimensions of the voussoirs should be determined both by geometrical drawings and numerical calculation, whenever the arch is important, or presents any complication of form. The drawings should, in the first place, be made to a scale sufficiently large to determine the parts with accuracy, and from these, pattern drawings giving the parts in their true size may be made for the use of the mason. To make the pattern drawings, the side of a vertical wall, or a firm horizontal area may be prepared, with a thin coating of mortar, to receive a thin smooth coat of plaster of Paris. The drawing may be made on this surface in the usual manner, by describing the curve either by points from its calculated abscissas and ordinates, or, where it is formed of circular arcs, by using the ordinary instrument for describing such arcs when the centres fall within the limits of the prepared surface. In ovals the positions of the extreme radii should be accurately drawn either from calculation, or construction. To construct the intermediate normals, whenever the centres of the arcs do not fall on the surface, an arc with a chord of about one foot, may be set off on each side of the point through which the normal is to be drawn, and the chord of the whole arc, thus set off, be bisected by a perpendicular. This construction will generally give a sufficiently accurate practical result for elliptical and other curves of a large size.

459. The masonry of arches may be either of dressed stone, rubble, or brick.

In wide spans, particularly for oval and other flat arches, cut stone should alone be used. The joints should be dressed with extreme accuracy. As the voussoirs have to be supported by a framing of timber, termed a *centre*, until the arch is completed, and as this structure is liable to yield, both from the elasticity of the materials and the number of joints in the frame, an allowance for the settling in the arch, arising from these causes, is sometimes made, in cutting the joints of the voussoirs *false*, that is, not according to the true position of the normal, but from the supposed position the joints will take when the arch has settled thoroughly. The object of this is to bring the surfaces of the joints into perfect contact when the arch has assumed its permanent state of equilibrium, and thus prevent the voussoirs from breaking by unequal pressures on their coursing joints. This is a problem of considerable difficulty, and it will generally be better to cut the joints true, and guard against settling and its effects by giving great stiffness to the centres, and by placing between the joints of those voussoirs, where the principal movement

takes place in arches, sheets of lead suitably hammered to fit the joint and yield to any pressure.

460. The manner of laying the voussoirs demands peculiar care, particularly in those which form the heads of the arch. The positions of the inner edges of the voussoirs are determined by fixed lines, marked on the abutments, or some other unmovea ble object, and the calculated distances of the edges from these lines. These distances can be readily set off by means of the level and plumb-line. The angle of each joint can be fixed by a quadrant of a circle, connected with a plumb-line, on which the position of each joint is marked.

461. Rubble stone is used only for very small arches which do not sustain much weight, or as a filling between a network of ring and string courses in large arches which sustain only their own weight. In each case the blocks of rubble should be roughly dressed with the hammer, and be laid in good hydraulic mortar.

462. Brick may be used alone, or in combination with cut stone, for arches of considerable size. When the thickness of a brick arch exceeds a brick and a half, the bond from the soffit outward presents some difficulties. If the bricks are laid in concentric layers, or *shells*, a continuous joint will be formed parallel to the surface of the soffit, which will probably yield when the arch settles, causing the shells to separate, (Fig. 48.) If the

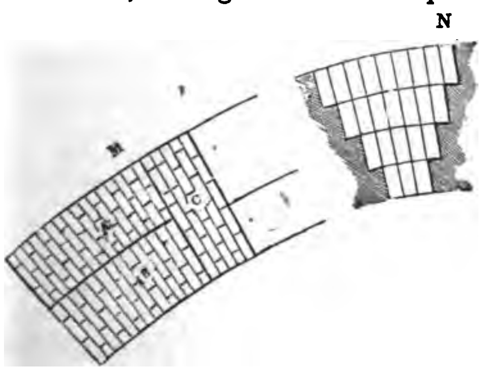


Fig. 48—Represents an end view M of a brick arch built with blocks C, and shells A, and B. N, represents the manner of arranging the courses of brick forming the crown of the arch.

bricks are laid like ordinary string courses, forming continuous joints from the soffit outward, these joints, from the form of the bricks, will be very open at the back, and, from the yielding of the mortar, the arch will be liable to injury in settling from this cause. To obviate both of these defects, the arch may be built partly by the first plan and partly by the second, or as it is termed, in shells and *blocks*. The crown, or key of the arch should be laid in a block, increasing the breadth of the block by two bricks for each course from the soffit outward. These bricks should be

laid in hydraulic cement, and be well wedged with pieces of thin hard slate between the joints.

463. When a combination of brick and cut stone is used, the ring courses of the heads, with some intermediate ring courses, the bottom string courses, the key-stone course, and a few intermediate string courses, are made of cut stone, (Fig. 49,) the

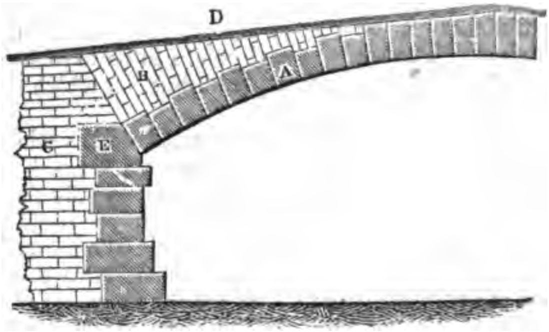


Fig. 49 — Represents a cross section of a stone segment arch capped with brick and beton. A, stone voussoirs. B and D, brick and beton capping. C, abutment. E, cushion stone.

intermediate spaces being filled in with brick. The brick portions of the soffit may, if necessary, be thrown within the stone portions, forming plain *caissons*.

464. The centres of small arches are not removed, or *struck* until the mortar has become hard; in large arches, the centres should not be struck until the whole of the mortar has set firmly. In the joints near the springing lines the mortar will have become hard, in the ordinary progress of building an arch, before that in the higher joints will have had time to set, unless hydraulic mortar of a quick set be used. After the centres are struck, the arch is allowed to assume its permanent state of equilibrium, before any of the superstructure is laid.

465. When the heads of the arch form a part of an exterior surface, as the faces of a wall, or the outer portions of a bridge, the voussoirs of the head ring courses are connected with the horizontal courses, as has been explained; the top surface of the voussoirs of the intermediate ring courses are usually left in a roughly dressed state to receive the courses of masonry termed the *capping*, (see Fig. 49,) which rests upon the arch between the walls of the head. Before laying the capping, the joints of the voussoirs on the back of the arch should be carefully examined, and, wherever they are found to be open from the settling of the arch, they should be filled up with soft-tempered mortar, and by driving in pieces of hard slate. The capping may be variously formed of rubble, brick, or beton. Where the arches are exposed to the filtration of rain water, as in those used for bridges, and the casemates of fortifications, the capping should be of beton

laid in layers, and well rammed with the usual precautions for obtaining a solid homogeneous mass.

466. The difficulty of forming water-tight cappings of masonry has led engineers, within a few years back, to try a coating of asphalte upon the surface of beton. The surface of the beton capping is made uniform and smooth by the trowel, or float, and the mass is allowed to become thoroughly dry before the asphalte is laid. Asphalte is usually laid on in two layers. Before applying the first, the surface of the beton should be thoroughly cleansed of dust, and receive a coating of mineral tar applied hot with a swab. This application of hot mineral tar is said to prevent the formation of air bubbles in the layers of asphalte which, when present, permit the water to percolate through the masonry. The first layer of asphalte is laid on in squares, or thin blocks, care being taken to form a perfect union between the edges of the squares by pouring the hot liquid along them in forming each new one. The surface of the first layer is made uniform, and rubbed until it becomes smooth and hard with an ordinary wooden float. In laying the second layer, the same precautions are taken as for the first, the squares breaking joints with those of the first. Fine sand is strewed over the surface of the top layer, and pressed into the asphalte before it becomes hard.

Coverings of asphalte have been used both in Europe and in our military structures for some years back with decided success. There have been failures, in some instances, arising in all probability either from using a bad material, or from some fault of workmanship.

467. In a range of arches, like those of bridges, or casemates, the capping of each arch is shaped with two inclined surfaces, like a common roof. The bottom of these surfaces, by their junction, form gutters where the water collects, and from which it is conveyed off in conduits, formed either of iron pipes, or of vertical openings made through the masonry of the piers which communicate with horizontal covered drains. A small arch of sufficient width to admit a man to examine its interior, or a square culvert, is formed over the gutter. When the spaces between the head walls above the capping is filled in with earth, a series of drains running from the top, or *ridge* of the capping, and leading into the main gutter drain, should be formed of brick. They may be best made by using dry brick laid flat, and with intervals left for the drains, these being covered by other courses of dry brick with the joints in some degree open. The earth is filled in upon the upper course of bricks, which should be so laid as to form a uniform surface.

468. When the space above the capping is not filled in with a solid mass, for the purpose of receiving the weight borne by the

arches, walls of a requisite height may be built parallel to the head walls, and these may serve either as the piers of small arches, (Fig. 50,) upon which the weight borne directly rests, or

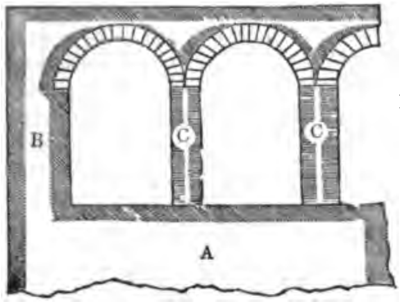


Fig. 50—Represents a section through a pier and the heads of an arch, showing the manner in which small arches are built on piers C, C, parallel to the head walls B, to sustain the load above the arch

else be covered by strong flat stones to effect the same object In this last case (Fig. 51) the walls may be made lighter by forming arched openings through them, or else a system of small right cylindrical groined arches may be used. All of these methods are in use in bridge building for sustaining the roadway, and also in roofing arched edifices. They throw less weight upon the abutments and piers of the arches than would a filling of solid material.

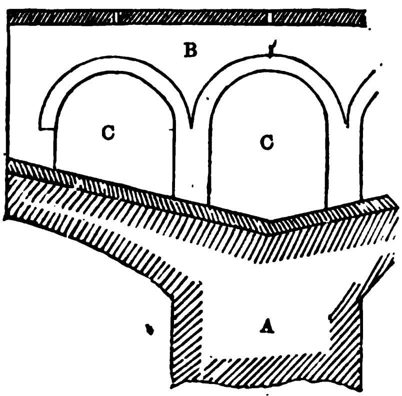


Fig. 51—Represents a cross section of the parts of two arches, and the pier A, showing the manner in which walls B, with arched openings C, C through them are built parallel to the heads, to receive the flat stones *a*, *a* which support the load above the arches.

469. From observations taken on the manner in which large cylindrical arches settle, and experiments made on a small scale, it appears that in all cases of arches where the rise is equal to or less than the half span they yield (Fig. 52) by the crown of the arch falling inward, and thrusting outward the lower portions, presenting five joints of rupture, one at the key stone, one on each side of it which limit the portions that fall inward, and one on each side near the springing lines which limit the parts thrust

outward. In pointed arches, or those in which the rise is greater

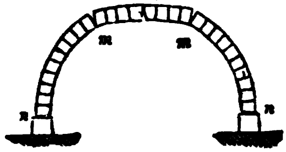


Fig. 52—Represents the manner in which flat arches yield by rupture.
o, joint of rupture at the key stone.
m, *m*, joints of rupture below the key stone.
n, *n*, joints of rupture at springing lines.

than the half span, the tendency to yielding is, in some cases, different; here the lower parts may fall inward, (Fig. 53,) and thrust upward and outward the parts near the crown.

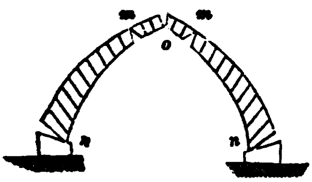


Fig. 53—Represents the manner in which pointed arches may yield.
The letters refer to same points as in Fig. 52.

470. From this movement in arches a pressure arises against the key stone, termed the *horizontal thrust* of the arch, the tendency of which is to crush the stone at the key, and to overturn the abutments of the arch, causing them to rotate about the exterior edge of some one of their horizontal joints.

471. The joints of rupture below the key stone vary in arches of different forms, and in the same arch with the weight it sustains. From experiments, it appears that in full centre arches the joints in question make an angle of about 27° with the horizon; in segment arches of arcs less than 120° they are at the springing lines; and in oval arches of three centres they are found about the angle of 45° of the small arc which forms the extremity of the curve at the springing line.

472. The calculation of the joints of rupture, the consequent horizontal thrust, and its effects in crushing the stone at the key and in overturning the abutment are problems of considerable mathematical intricacy. When the joints of rupture are given the problem assumes a more simple form, being one of statical equilibrium between the moments of the horizontal thrust and the weight of the arch and its abutments.

The problem for finding the joints of rupture by calculation, and the consequent thickness of the abutments necessary to preserve the arch from yielding, has been solved by a number of writers on the theory of the equilibrium of arches, and tables for effecting the necessary numerical calculations have been drawn up from their results to abridge the labor in each case.

473. The connection between the top of the abutment, termed the *impost* of the arch, and the bottom courses of the arch,

requires peculiar care in segmental, askew, and rampant arches. In the first, the thrust of the arch being very great, it will be well, in heavy arches, to make the joints of the interior courses of the abutment, for some courses at least below the impost, oblique to the horizon to counteract any danger from sliding. The top stone of the abutment, termed the *cushion stone* of the arch, should be well bonded with the stones of the backing, and its bed, or bottom joint should be so far below the impost joint, that the stone shall offer sufficient strength to resist the pressure on it.

In the askew arch the abutments are not uniformly loaded, and the entire thrust of the arch will not be received by the abutments if the arch is constructed in the usual manner. Each of these points requires peculiar attention; the first demanding the thickness of the abutment to be suitably regulated; the second that the arch be so built that the thrust may be thrown, as nearly as practicable, parallel to the planes of the heads. To effect this last point, the portion of the arch above the upper joints of rupture (Fig. 54,) must be divided into several zones, each of these zones being built without any connection with the two adjacent to it, but with their ends so arranged that this connection may be formed, and the arch made continuous after the

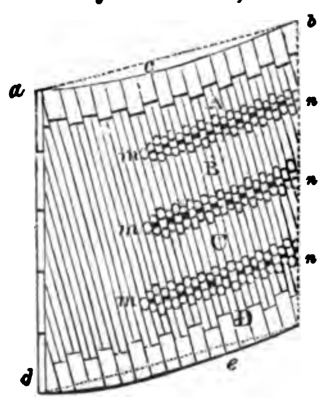


Fig. 54—Represents the development of half of the soffit of an oblique cylindrical arch with helicoidal joints, showing the divisions of the soffit into zones A, B, C, D by a series of heading joints *mn* laid open without mortar.
acb, development of curve of oblique section.
ce, one of the edges of the coursing joints perpendicular to the right line *ab*.
ad, springing line of arch.

centres are struck. By this plan the settling will take place after uncentring without causing cracks, and the thrust will be thrown on the abutments in the direction desired.

In rampant arches, the impost joint being oblique to the horizon, care must be taken, if this obliquity be not less than the angle of friction of the stone used, either to cut the impost into steps, or else to use some suitable bond, or iron cramps and bolts to prevent disjunction between the arch and abutment.

474. The abutments of right and of slightly oblique cylindrical arches are made of uniform dimensions; but when the ob

liquity is considerable, it may be necessary to increase the thickness of a portion of each abutment where there is the greatest pressure.

In conical and conoidal arches the abutments will in like manner vary in dimensions with the span.

475. In cloistered arches the abutments will be less than in an ordinary cylindrical arch of the same length; and in groined arches, in calculating the resistance offered by the abutments, the counter resistance offered by the weight of one portion in resisting the thrust of the other, must be taken into consideration.

476. When abutments, as in the case of edifices, require to be of considerable height, and therefore would demand extraordinary thickness, if used alone to sustain the thrust of the arch, they may be strengthened by the addition to their weight made in carrying them up above the imposts like the *battlements* and *pinnacles* in Gothic architecture; by adding to them ordinary, full, or arched buttresses, termed *flying buttresses;* or by using ties of iron connecting the voussoirs near the joints of rupture below the key stone. The employment of these different expedients, their forms and dimensions, will depend on the character of the structure and the kind of arch. The iron tie, for example, cannot be hidden from view except in the plate-bande, or in very flat segment arches, and wherever its appearance would be unsightly some other expedient must be tried.

Circular rings of iron have been used to strengthen the abutments of domes, by confining the lower courses of the dome and relieving the abutment from the thrust.

477. When abutments sustain several arches above each other, like relieving arches in tiers, their dimensions must be calculated to sustain the united thrusts of the arches; and the several portions between each tier must be strong enough to resist the thrust of their corresponding arches.

478. In a range of arches of unequal size, the piers will have to sustain a lateral pressure occasioned by the unequal horizontal thrust of the arches. In arranging the form and dimensions of the piers this inequality of thrust must be estimated for, taking also into consideration the position of the imposts of the unequal arches.

479. *Precautions against Settling.* One of the most difficult and important problems in the construction of masonry, is that of preventing unequal settling in parts which require to be connected but sustain unequal weights, and the consequent ruptures in the masses arising from this cause. To obviate this difficulty requires on the part of the engineer no small degree of practical tact. Several precautions must be taken to diminish as far as practicable the danger from unequal settling. Walls sustaining

heavy vertical pressures should be built up uniformly, and with great attention to the bond and correct fitting of the courses. The materials should be uniform in quality and size; hydraulic mortar should alone be used; and the permanent weight not be laid on the wall until the season after the masonry is laid. As a farther precaution, when practicable, a trial weight may be laid upon the wall before loading it with the permanent one.

Where the heads of arches are built into a wall, particularly if they are designed to bear a heavy permanent weight, as an embankment of earth, the wall should not be carrried up higher than the imposts of the arches until the settling of the latter has reached its final term; and as there will be danger of disjunction between the piers of the arches and the wall at the head, from the same cause, these should be carried up independently, but so arranged that their after-union may be conveniently effected. It would moreover be always well to suspend the building of the arches until the season following that in which the piers are finished, and not to place the permanent weight upon the arches until the season following their completion.

480. *Pointing*. The mortar in the joints near the surfaces of walls exposed to the weather should be of the best hydraulic lime, or cement, and as this part of the joint always requires to be carefully attended to, it is usually filled, or as it is termed *pointed*, some time after the other work is finished. The period at which pointing should be done is a disputed subject among builders, some preferring to point while the mortar in the joint is still fresh, or *green*, and others not until it has become hard. The latter is the more usual and better plan. The mortar for pointing should be poor, that is, have rather an excess of sand; the sand should be of a fine uniform grain, and but little water be used in tempering the mortar. Before applying the pointing, the joint should be well cleansed by scraping and brushing out the loose matter, and then be well moistened. The mortar is applied with a suitable tool for pressing it into the joint, and its surface is rubbed smooth with an iron tool. The practice among our military engineers is to use the ordinary tools for calking in applying pointing; to calk the joint with the mortar in the usual way, and to rub the surface of the pointing until it becomes hard. To obtain pointing that will withstand the vicissitudes of our climate is not the least of the difficulties of the builder's art. The contraction and expansion of the stone either causes the pointing to crack, or else to separate from the stone, and the surface water penetrating into the cracks thus made, when acted upon by frost throws out the pointing. Some have tried to meet this difficulty by giving the surface of the pointing such a shape, and so arranging it with respect to the surfaces of the stones forming the

joint, that the water shall trickle over the pointing without entering the crack which is usually between the bed of the stone and the pointing.

481. The term *flash pointing* is sometimes applied to a coating of hydraulic mortar laid over the face, or back of a wall, to preserve either the mortar joints, or the stone itself from the action of moisture, or the effects of the atmosphere. Mortar for flash pointing should also be made poor, and when it is used as a stucco to protect masonry from atmospheric action, it should be made of coarse sand, and be applied in a single uniform coat over the surface, which should be prepared to receive the stucco by having the joints thoroughly cleansed from dust and loose mortar, and being well moistened.

No pointing of mortar has been found to withstand the effects of weather in our climate on a long line of coping. Within a few years a pointing of asphalte has been tried on some of our military works, and has given thus far promise of a successful issue.

482. Stucco exposed to weather is sometimes covered with paint, or other mixtures, to give it durability. Coal tar has been tried, but without success in our climate. M. Raucourt de Charleville, in his work *Traité des Mortiers*, gives the following compositions for protecting exposed stuccoes, which he states to succeed well in all climates. For important work, three parts of linseed oil boiled with one sixth of its weight of litharge, and one part of wax. For common works, one part of linseed oil, one tenth of its weight of litharge, and two or three parts of resin.

The surfaces must be thoroughly dry before applying the compositions, which should be laid on hot with a brush.

483. *Repairs of Masonry.* In effecting repairs in masonry, when new work is to be connected with old, the mortar of the old should be thoroughly cleaned off wherever it is injured along the surface where the junction is effected. The bond and other arrangements will depend upon the circumstances of the case; the surfaces connected should be fitted as accurately as practicable, so that by using but little mortar, no disunion may take place from settling.

484. An expedient, very fertile in its applications to hydraulic constructions, has been for some years in use among the French engineers, for stopping leaks in walls and renewing the beds of foundations which have yielded, or have been otherwise removed by the action of water. It consists in injecting hydraulic cement into the parts to be filled, through holes drilled through the masonry, by means of a strong syringe. The instruments used for this purpose (Fig. 55) are usually cylinders of wood, or of cast iron; the bore uniform, except at the end which is terminated with a nozle of the usual conical form; the piston is of wood

and is driven down by a heavy mallet. In using the syringe it is adjusted to the hole; the hydraulic cement in a semi-fluid

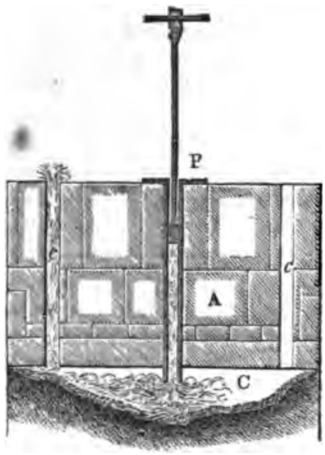


Fig. 55—Represents the arrangements for injecting hydraulic cement under a wall.
A, section of the wall with vertical holes *c*, *c* drilled through it.
B, syringe and piston for injecting the cement into the space C under the wall.

state poured into it; a wad of tow, or a disk of leather being introduced on top before inserting the piston. The cement is forced in by repeated blows on the piston.

485. A mortar of hydraulic lime and fine sand has been used for the same purpose; the lime being ground fresh from the kiln, and used before slaking, in order that by the increase of volume which takes place from slaking, it might fill more compactly all interior voids. The use of unslaked lime has received several ingenious applications of this character; its after expansion may prove injurious when confined. The use of sand in mortar for injections has by some engineers been condemned, as from the state of fluidity in which the mortar must be used, it settles to the bottom of the syringe, and thus prevents the formation of a homogeneous mass.

486. *Effects of Temperature on Masonry.* Frost is the most powerful destructive agent against which the engineer has to guard in constructions of masonry. During severe winters in the northern parts of our country, it has been ascertained, by observation, that the frost will penetrate earth in contact with walls to depths exceeding ten feet; it therefore becomes a matter of the first importance to use every practicable means to drain thoroughly all the ground in contact with masonry, to whatever depths the foundations may be sunk below the surface; for if this precaution be not taken, accidents of the most serious nature may happen to the foundations from the action of the frost. If water collects in any quantity in the earth around the foundations, i

may be necessary to make small covered drains under them to convey it off, and to place a stratum of loose stone between the sides of the foundations and the surrounding earth to give it a free downward passage.

It may be laid down as a maxim in building, that mortar which is exposed to the action of frost before it has set, will be so much damaged as to impair entirely its properties. This fact places in a stronger light what has already been remarked, on the necessity of laying the foundations and the structure resting on them in hydraulic mortar, to a height of at least three feet above the ground, for, although the mortar of the foundations might be protected from the action of the frost by the earth around them, the parts immediately above would be exposed to it, and as those parts attract the moisture from the ground, the mortar, if of common lime, would not set in time to prevent the action of the frosts of winter.

In heavy walls the mortar in the interior will usually be secured from the action of the frost, and masonry of this character might be carried on until freezing weather commences; but still in all important works it will be by far the safer course to suspend the construction of masonry several weeks before the ordinary period of frost.

During the heats of summer, the mortar is injured by a too rapid drying. To prevent this the stone, or brick, should be thoroughly moistened before being laid; and afterwards, if the weather is very hot, the masonry should be kept wet until the mortar gives indications of setting. The top course should always be well moistened by the workmen on quitting their work for any short period during very warm weather.

The effects produced by a high or low temperature on mortar in a green state are similar. In the one case the freezing of the water prevents a union between the particles of the lime and sand; and in the other the same arises from the water being rapidly evaporated. In both cases the mortar when it has set is weak and pulverulent.

FRAMING

487. FRAMING is the art of arranging beams of solid materials for the various purposes to which they are applied in structures. A *frame* is any arrangement of beams made for sustaining strains.

488. That branch of framing which relates to the combinations of beams of timber is denominated *Carpentry*.

489. Timber and iron are the only materials in common use for frames, as they are equally suitable to resist the various strains to be met with in structures. Iron, independently of offering greater resistance to strains than timber, possesses the farther advantage of being susceptible of receiving the most suitable forms for strength without injury to the material; while timber, if wrought into the best forms for the object in view may, in some cases, be greatly injured in strength.

490. The object to be attained in framing is to give, by a suitable combination of beams, the requisite degree of strength and stiffness demanded by the character of the structure, united with a lightness and an economy of material of which an arrangement of a massive kind is not susceptible. To attain this end, the beams of the frame must be of such forms, and be so combined that they shall not only offer the greatest resistance to the efforts they may have to sustain, but shall not change their relative positions from the effect of these efforts.

491. The forms of the beams will depend upon the kind of material used, and the nature of the strain to which it may be subjected, whether of tension, compression, or a cross strain.

492. The general shape given to the frame, and the combinations of the beams for this purpose, will depend upon the object of the frame and the directions in which the efforts act upon it.

In frames of timber, for example, the cross sections of each beam are generally uniform throughout, these sections being either circular, or rectangular, as these are the only simple forms which a beam can receive without injury to its strength. In frames of cast iron, each beam may be cast into the most suitable form for the strength required, and the economy of the material.

493. In combining the beams, whatever may be the general shape of the frame, the parts which compose it must, as far as practicable, present triangular figures, each side of the triangles being formed of a single beam; the connection of the beams at the angular points, termed the *joints*, being so arranged that no yielding can take place. In all combinations, therefore, in which

he principal beams form polygonal figures, secondary beams must be added, either in the directions of the diagonals of the polygon, or so as to connect each pair of beams forming an angle of the polygon, for the purpose of preventing any change of form of the figure, and of giving the frame the requisite stiffness. These secondary pieces receive the general appellation of *braces*. When they sustain a strain of compression they are termed *struts*; when one of extension, *ties*.

494. As one of the objects of a frame is to transmit the strain it directly receives to firm points of support, the beams of which it is formed should be so combined that this may be done in the way which shall have the least tendency to change the shape of the frame, and to fracture the beams. These conditions will be best satisfied by giving the principal beams of the frame a position such that the strains they receive shall be transmitted through the axes of the beams to the fixed supports; in this manner there can be no tendency to change the shape of the frame, except so far as this may arise from the contractions, or elongations of the beams, caused by the strains; and as all unnecessary transversal strains will in like manner be avoided, the resistances offered by the beams will be the greatest practicable.

495. Whenever these conditions cannot be satisfied, the strains on the frame should be so combined that those which are not transmitted to the points of support shall balance, or destroy each other; and those beams which, from being subjected to a cross strain, might be either in danger of rupture, or of being deflected to so great a degree as to injure the stability of the frame, should be supported by struts abutting either against fixed supports, or against points of the frame where the pressure thrown upon the strut would have no effect in changing the shape of the frame.

496. The points of support of a frame may be either above, or below it. In the first case, the frame will consist of a suspended system, in which the polygon will assume a position of stable equilibrium, its sides being subjected to a strain of extension. In the second case the frame, if of a polygonal form, must satisfy the essential conditions already enumerated, in order that its state of equilibrium shall be stable.

497. The strength of the frame and that of its parts, and their consequent dimensions, must be regulated by the strains to which they are subjected. When the form of the frame and the direction and amount of the strain borne by it are given, the direction and amount of the strain which the different parts sustain can be ascertained by the ordinary laws of statics, and, from these data, the requisite dimensions and forms of the parts.

498. The object of the structure will necessarily decide the general shape of the frame, as well as the direction of the strains

to which it will be subjected. An examination, therefore, of the frames adapted to some of the more usual structures will be the best course for illustrating both the preceding general principles and the more ordinary combinations of the beams and joints.

499. *Frames of Timber.* These are composed either entirely of straight beams, or of a combination of straight beams and of arches formed by bending straight beams.

Pieces of crooked timber are used either where the form of the parts requires them, or else where a strong connection is necessary between straight pieces that form an angle between them.

500. As has already been stated, the cross section of each beam is generally uniform and rectangular. This will, in some cases, give more strength than the character of the strain resisted may demand; and will, also, throw a greater amount of pressure on the points of support, than if beams of a form more strictly adapted to the object in view were used: but it avoids cutting the fibres across the grain, or making, as it is termed, *grain-cut* beams, and thereby materially injuring the strength of the piece. This objection, however, is only applicable to the parts of a frame formed of single beams. Wherever several thicknesses of beams are required in the arrangement of any part, the advantage may be taken of giving the combination the most suitable form for strength and lightness combined.

501. *Frames for Cross Strains.* The parts of a frame which receive a cross strain may be horizontal, as the beams, or *joists* of a floor; or inclined, as the beams, or *rafters* which form the inclined sides of the frame of a roof. The pressure producing the cross strain may either be uniformly distributed over the beams, as in the cases just cited, arising from the flooring boards in the one case, and the roof covering in the other; or it may act only at one point, as in the case of a weight laid upon the beam.

In all of these cases the extremities of the beam must be firmly fixed against immoveable points of support; the longer side of the rectangular section of the beam should be parallel to the direction of the strain, on account of placing the beam in the best position for strength.

If the distance between the points of support, or the *bearing*, be not great, the framing may consist simply of a row of parallel beams of such dimensions, and placed so far asunder as the strain borne may require. When the beams are narrow, or the depth

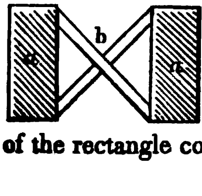


Fig. 56—Represents a cross section of horizontal beams *a a* braced by diagonal battens *b*.

of the rectangle considerably greater than the breadth, (Fig. 56,)

short struts of battens may be placed at intervals between each pair of beams, in a diagonal direction, uniting the bottom of the one with the top of the other, to prevent the beams from twisting, or yielding laterally.

When the bearing and strain are so great that a single beam will not present sufficient strength and stiffness, a combination of beams, termed a *built beam*, which may be *solid*, consisting of several layers of timber laid in juxtaposition, and firmly connected together by iron bolts and straps,—or *open*, being formed of two beams, with an interval between them, so connected by cross and diagonal pieces, that a strain upon either the upper or lower beam will be transmitted to the other, and the whole system act under the effect of the strain like a solid beam.

502. *Solid built Beams.* In framing solid built beams, the pieces in each course (Fig. 57) are laid abutting end to end with

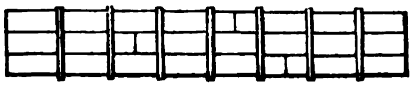


Fig. 57—Represents a solid built beam of three courses, the pieces of each course breaking joints and confined by iron hoops.

a square joint between them, the courses breaking joints to form a strong bond between them. The courses are firmly connected either by iron bolts, formed with a screw and nut at one end to bring the courses into close contact, or else by iron bands driven on tight, or by iron stirrups (Fig. 58) suitably arranged with screw ends and nuts for the same purpose.

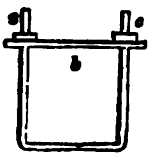


Fig. 58—Represents an iron stirrup, or hoop *a* with nuts or female screws *c* which confine the cross piece of the stirrup *b*

When the strain is of such a character that the courses would be liable to work loose and slide along their joints, the beams of the different courses may be made with shallow indentations, (Figs. 59, 60,) accurately fitting into each other; or shallow rec-

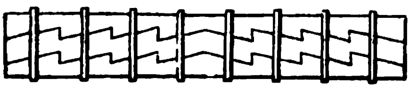


Fig. 59—Represents a solid built beam of three courses arranged with indents and confined by iron hoops.

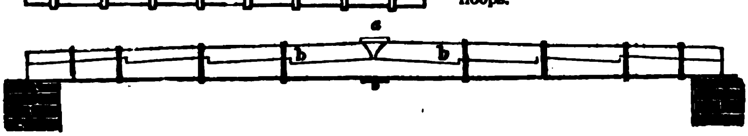


Fig. 60—Represents a solid built beam, the top part being of two pieces *b*, *b* which abut against a broad flat iron bolt *a*, termed a *king bolt*.

tangular notches (Fig. 61) may be cut across each beam, being

so placed as to receive blocks, or *keys* of hard wood. The keys

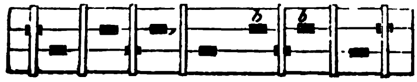


Fig. 61—Represents a solid built beam with keys *b*, *b* of hard wood between the courses.

are sometimes made of two wedge-shaped pieces, (Fig. 62,) for

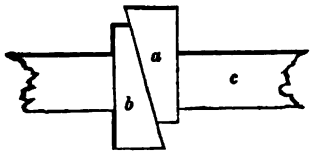


Fig. 62—Represents the keys in the form of double, or *folding* wedges *a*, *b* let into a shallow notch in the beam *c*.

the purpose of causing them to fit the notches more closely, and to admit of being driven tight upon any shrinkage of the woody fibre.

The joints between the courses may be left slightly open without impairing in an appreciable degree the strength of the combination. This is a good method in beams exposed to moisture, as it allows of evaporation from the free circulation of the air through the joints. Felt, or stout paper saturated with mineral tar, has been recommended to secure the joints from the action of moisture. The prepared material is so placed as to occupy the entire surface of the joint, and the whole is well screwed together.

503. *Open built Beams.* In framing open built beams, the principal point to be kept in view is to form such a connection between the upper and lower solid beams, that they shall be strained uniformly by the action of a strain at any point between the bearings. This may be effected in various ways, (Fig. 63.)

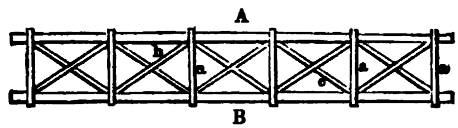


Fig. 63—Represents an open built beam; A and B are the top and bottom rails or strings; *a*, *a*, cross pieces, either single or in pairs; *b*, diagonal braces in pairs; *c*, single diagonal braces.

The upper and lower beams may consist either of single beams, or of solid built beams; these are connected at regular intervals by pieces at right angles to them, between which diagonal pieces are placed. By this arrangement the relative position of all the parts of the frame will be preserved, and the strain at any point will be brought to bear upon the intermediate points.

Two of the best known applications of this combination, when timber alone is used, are those of Colonel Long, of the U. S. Topographical Engineers, and of the late Mr. Town.

504. That of Colonel Long (Fig. 64) consists in forming both the upper and lower beams, termed by the inventor the *strings*,

of three parallel beams, sufficient space being left between the one in the centre and the other two to insert the cross pieces,

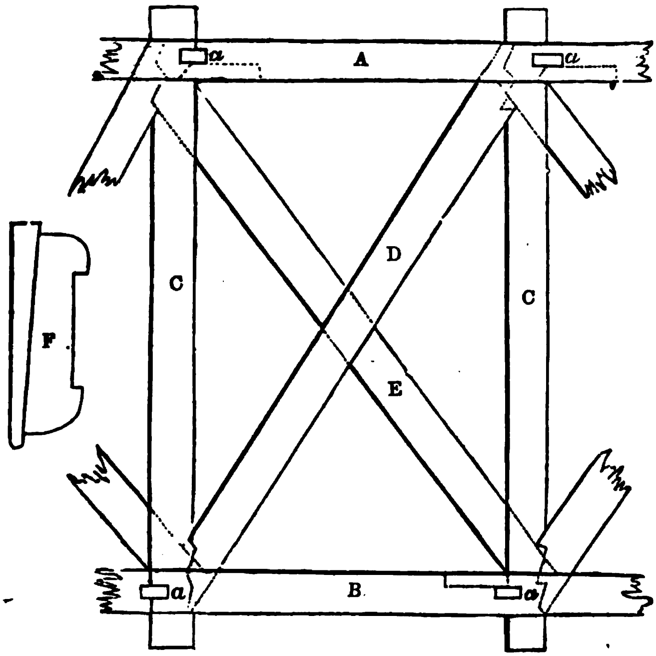


Fig. 64—Represents a panel of Long's truss.
A and B, top and bottom strings of three courses
C, C, posts in pairs.
D, braces in pairs.
E, counter brace single.
a, a, mortises where jibs and keys are inserted
F, jib and key of hard wood.

termed the *posts;* the posts consist of beams in pairs placed at suitable intervals along the strings, with which they are connected by wedge blocks, termed *jibs* and *keys*, which are inserted into rectangular holes made through the strings, and fitting a corresponding shallow notch cut into each post. A diagonal piece, termed a *brace*, connects the top of one post with the foot of the one adjacent by a suitable joint. Another diagonal piece, termed the *counter-brace*, is placed crosswise between the two braces and their posts, with its ends abutting against the centre beam of the upper and lower strings. The counter-braces are connected with the posts and braces by wooden pins, termed *tree-nails*.

In wide bearings, the strings will require to be made of several beams abutting end to end; in this case the beams must break

joints, and short beams must be inserted between the centre and exterior beams wherever the joints occur, to strengthen them.

The beams in this combination are all of uniform cross section, the joints and fastenings are of the simplest kind, and the parts are well distributed to call into play the strength of the strings, and to produce uniform stiffness and strain.

505. The combination of Mr. Town (Fig. 65) consists in two

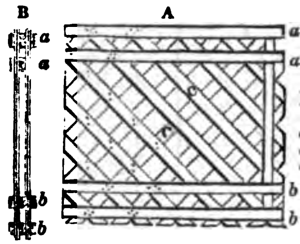


Fig. 65—Represents an elevation A, and end view B, of a portion of Town's truss.
a, *a*, top strings.
b, *b*, bottom strings.
c, *c*, diagonal braces

main strings, each formed of two or three parallel beams of two thicknesses breaking joints. Between the parallel beams are inserted a series of diagonal beams crossing each other. These diagonals are connected with the strings and with each other by tree-nails. When the strings are formed of three parallel beams, diagonal pieces are placed between the centre and exterior beams, and two intermediate strings are placed between the two courses of diagonals.

This combination, commonly known as the *lattice* truss, is of very easy mechanical execution, the beams being of a uniform cross section and length. The strains upon it are borne by the tree-nails, and when used for structures subjected to variable strains and jars, it loses its stiffness and sags between the points of support. It is more recommendable for its simplicity than scientific combination.

506. A third method, called after the patentee, *How's* truss, has within a few years come into general notice. It consists of (Fig. 66) an upper and lower string, each formed of several thicknesses of beams placed side by side and breaking joints. On the upper side of the lower string and the lower side of the upper, blocks of hard wood are inserted into shallow notches; the blocks are bevelled off on each side to form a suitable point of support, or *step* for the diagonal pieces. One series of the diagonal pieces are arranged in pairs, the others are single and placed between those in pairs. Two strong bolts of iron, which pass through the blocks, connect the upper and lower strings, and are arranged with a screw cut on one end and a nut to draw the parts closely together.

This combination presents a judicious arrangement of the parts The blocks give abutting surfaces for the braces superior to those

obtained by the ordinary forms of joint for this purpose. The bolts replace advantageously the timber posts, and in case of the

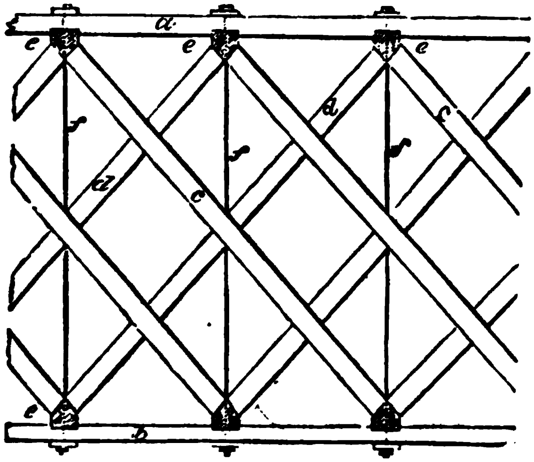


Fig. 66—Represents an elevation of a portion of Howe's truss.
a, top string.
b, bottom strings.
c, c, diagonal braces in pairs.
d, single braces.
e, e, steps of hard wood for braces.
f, f, iron rods with nuts and screws

frame working loose and sagging, their arrangement for tightening up the parts is simple and efficacious. The timber of each string is not combined to give as great strength as its cross section is susceptible of, and the lower string, upon which a strain of tension is brought, against which timber offers the greatest resistance, has received a greater cross section than that of the upper.

The preceding combinations have been applied generally in our country to bridges. In this application, the timber supporting the roadway of the bridge is usually placed on the lower strings; two, three, or four built beams being used, as the case may require, for supporting the transverse beams under the roadway, the centre beams leaving an equal width of roadway between them and the exterior beams.

507. *Framing for intermediate Supports.* Beams of ordinary dimensions may be used for wide bearings when intermediate supports can be procured between the extreme points.

The simplest and most obvious method of effecting this is to place upright beams, termed *props*, or *shores*, at suitable intervals under the supported beam.

When the props would interfere with some other arrangement, and points of support can be procured at the extremities below those on which the beam rests, inclined struts (Fig. 67) may be used. The struts must have a suitably formed step at the foot, and be connected at top with the beam by a suitable joint.

In some cases the bearing may be diminished by placing on

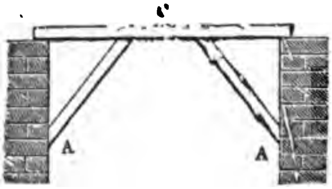


Fig. 67—Represents a horizontal beam C supported near the middle by inclined struts A, A.

the points of support short pieces, termed *corbels*, (Fig. 68,) and supporting these near their ends by struts.

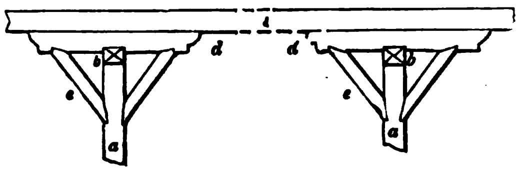


Fig. 68—Represents a horizontal beam *c* supported by vertical post *a*, *a*, with corbel pieces *d*, *d* and inclined struts *e*, *e* to diminish the bearing.

In other cases a portion of the beam, at the middle, may be strengthened by placing under it a short beam, called a *straining beam*, (Fig. 69,) against the ends of which the struts abut.

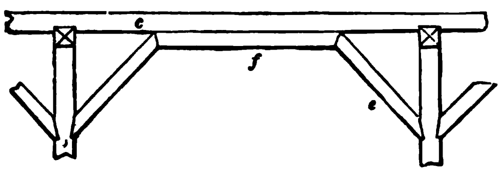


Fig. 69—Represents a horizontal beam *c*, strengthened by a straining beam *f* and inclined struts *e*, *e*.

Whenever the bearing may require it the two preceding arrangements (Fig. 70) may be used in connection.

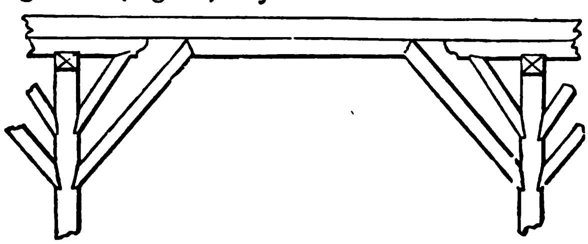


Fig. 70—Represents a combination of Figs. 68 and 69.

In all combinations with struts, a lateral thrust will be thrown on the point of support where the foot of the strut rests. This strain must be provided for in arranging the strength of the supports.

508. When intermediate supports can be procured only above the beam, an arrangement must be made which shall answer the purpose of sustaining the beam at its intermediate points by suspension. The combination will depend upon the number of intermediate points required.

When the beam requires to be supported only at the middle, it may be done by placing two inclined pieces, resting on the beam at its extremities, and meeting under an angle above it, from which the middle of the beam can be suspended by a rod of iron, or by another beam. If the suspending piece be of iron, it must be arranged at one end with a screw and nut. When the support is of timber, a single beam, called a *king post*, (Fig. 71,)

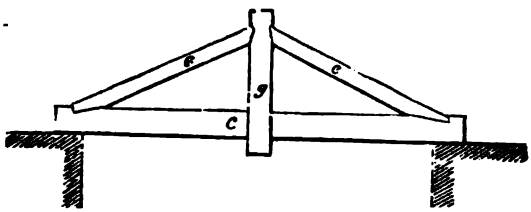


Fig. 71—Represents a horizontal beam *c* supported in its middle by a king post *g* suspended from the struts *e*, *e*.

may be used, against the head of which the two inclined pieces may abut; the foot of the post is connected with the beam by a bolt, an iron stirrup, or a suitable joint. Instead of the ordinary king post, two beams may be used; these are placed opposite to each other and bolted together, embracing between them the supported beam and the heads of the inclined beams which fit into shallow notches cut into the supporting beams. Pieces arranged in this manner for suspending portions of a frame receive the name of *suspension pieces*, or *bridle pieces*.

When two intermediate points of support are required, they may be obtained by two inclined pieces resting on the ends of the beam and abutting against the extremities of a short horizontal straining beam, (Fig. 72.) The suspension pieces in this case

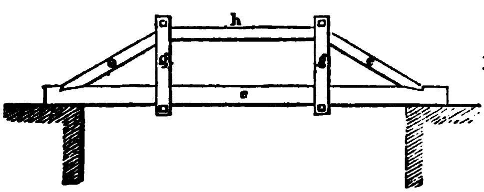


Fig. 72—Represents a beam *c* supported at two points by posts *g*, *g* suspended from the struts *e*, *e* and straining beam *h*.

may be either posts, termed *queen posts*, arranged like a king post, iron rods, or bridle pieces. This combination may be used for very wide bearings, (Fig. 73,) by suitably increasing the number of inclined pieces and straining beams.

Some of the preceding combinations may be used for supporting one end of a beam subjected to a cross strain when the other has a fixed point of support. This may be done either by an inclined strut beneath, or an inclined tie above the beam. When a wooden tie is used it should consist of two pieces bolted together and embracing the beam.

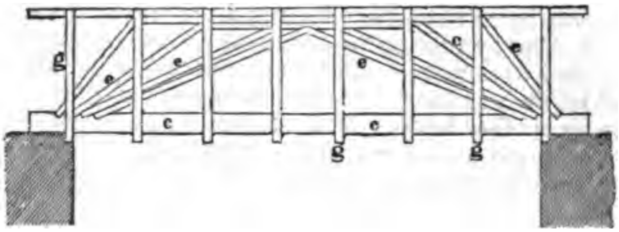


Fig. 73—Represents a beam *c* suspended from a combination of struts and straining beams by posts *g*, *g*.

509. The classifications under the two preceding heads represent the principal combinations of straight beams applied to the purposes of framing. The frame of an ordinary roof presents one of the simplest combinations by which the action of the different parts of a frame may be illustrated.

A roof of the ordinary form consists of two equally inclined sides of metal, slate, or other material, which is attached to a covering of boards that rests upon the frame of the roof. The frame consists of several vertical frames, termed the *trusses* of the roof, which are placed parallel to and at suitable intervals from each other; these receive horizontal beams termed *purlins*, which rest upon them and are placed at suitable intervals apart, and upon the purlins are placed inclined pieces termed the *long rafters*, to which the boards are attached.

The truss of a roof, for ordinary bearings, consists (Fig. 74)

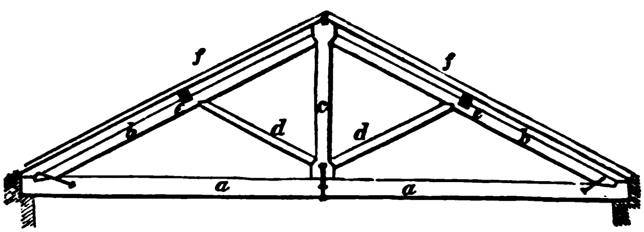


Fig 74—Represents a roof truss for medium spans.
a, tie beam of truss.
b, *b*, principal rafters framed into tie beam and the king post *c*, and confined at their foot by an iron strap.
d, *d*, struts.
e, *e*, purlins supporting the common rafters *f*, *f*.

of a horizontal beam termed the *tie beam*, with which the inclined beams, termed the *principal rafters*, are connected by suitable joints. The principal rafters may either abut against each other at the top or *ridge*, or against a king post. Inclined struts are in some cases placed between the principal rafters and king post, with which they are connected by suitable joints.

For wider bearings the short rafters (Fig. 75) abut against a

straining beam at top. Queen posts connect these pieces with the tie-beam. A king post connects the straining beam with the

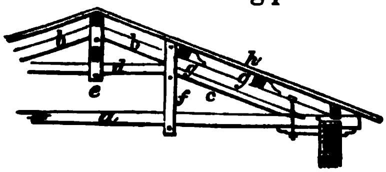


Fig. 75—Represents a roof truss for wide spans.
a, tie beam.
b, b, principal rafters.
c, short rafters abutting against the straining beam d.
e and f, king and queen posts in pairs.
g, g, purlins supporting common rafters h.

top of the short rafters; and struts are placed at suitable points between the rafters and king and queen posts.

In each of these combinations the weight of the roof covering and the frames is supported by the points of support. The principal rafters are subjected to cross and longitudinal strains, arising from the weight of the roof covering and from their reciprocal action on each other. These strains are transmitted to the tie beam, causing a strain of tension upon it. The struts resist the cross strain upon the rafters and prevent them from sagging; and the king and queen posts prevent the tie and straining beams from sagging aud give points of support to the struts. The short rafters and straining beam form points of support which resist the cross strain on the principal rafters, and support the strain on the queen posts.

510. *Wooden Arches.* A wooden arch may be formed by bending a single beam (Fig. 76) and confining its extremities to

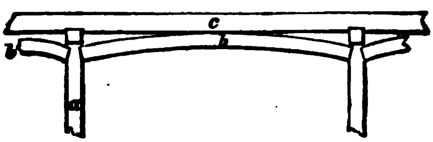


Fig. 76—Represents a horizontal beam c supported at its middle point by a bent beam b.

prevent it from resuming its original shape. A beam in this state presents greater resistance to a cross strain than when straight, and may be used with advantage where great stiffness is required, provided the points of support are of sufficient strength to resist the lateral thrust of the beam. This method can be resorted to only in narrow bearings.

For wide arches a curved built beam must be adopted; and for this purpose a solid, (Figs. 77 and 78,) or an open built beam may be used, depending on the bearing to be spanned by the arch. In either case the curved beams are built in the same manner as straight beams, the pieces of which they are formed being suitably bent to conform to the curvature of the arch, which may be done either by steaming the pieces, by mechanical power, or by the usual method of softening the woody fibres by keeping the pieces wet while subjected to the heat of a light blaze.

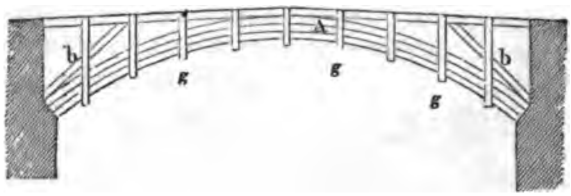


Fig. 77—Represents a wooden arch A formed of a solid built beam of three courses which support the beams c, c by the posts g, g which are formed of pieces in pairs.
b, b, inclined struts to strengthen the arch by relieving it of a part of the load on the beams c, c.

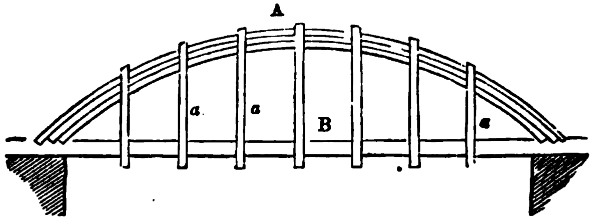


Fig. 78—Represents a wooden arch of a solid built beam A which supports the horizontal beam B by means of the posts a, a. The arch is let into the beam B which acts as a tie to confine its extremities.

Wooden arches may also be formed by fastening together several courses of boards, giving the frame a polygonal form, (Fig. 79,) corresponding to the desired curvature, and then shaping the

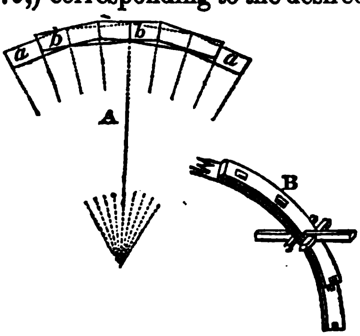


Fig. 79—Represents an elevation A of a wooden arch formed of short pieces a, b which abut end to end and break joints.
B represents a perspective view of this combination, showing the manner in which the parts are keyed together.

outer and inner edges of the arch to the proper curve. Each course is formed of boards cut into sharp lengths, depending on the curvature required; these pieces abut end to end, the joints being in the direction of the radii of curvature, and the pieces composing the different courses break joints with each other. The courses may be connected either by jibs and keys of hard wood, or by iron bolts. This method is very suitable for all light frame work where the presure borne is not great.

Wooden arches are chiefly used for bridges and roofs. They

serve as intermediate points of support for the framing on which the roadway rests in the one case, and the roof covering in the other. In bridges the roadway may lie either above the arch, or below it; in either case vertical posts, iron rods, or bridles connect the horizontal beams with the arch.

511. The greatest strain in wooden arches takes place between the crown and springing line; this part should, therefore, when practicable, be relieved of the pressure that it would directly receive from the beams above it by inclined struts, so arranged as to throw this pressure upon the lateral supports of the arch.

The pieces which compose a wooden arch may be bent into any curve. The one, however, usually adopted is an arc of a circle, as the most simple for the mechanical construction of the framing, and presenting all desirable strength.

612. *Centres.* The wooden frame with which the voussoirs of an arch are supported while the arch is in progress of construction is termed a *centre.*

A centre, like the frame of a roof, consists of a number of vertical frames (Figs. 80, 81, 82, 83,) termed trusses, or *ribs*, upon which horizontal beams, termed *bolsters*, are placed to receive the voussoirs of the arch.

The curved, or *back* pieces of a centre on which the bolsters rest consist of beams cut into suitable lengths and shaped to the proper curvature; these pieces abut end to end, the joints between them being in the direction of the radii of curvature; the joints are usually secured by short pieces, or blocks placed under the abutting ends to which the back pieces are bolted. The blocks form abutting surfaces for shores, or inclined struts seated against firm points of support below the back pieces. To prevent the shores, or the struts from bending, braces, or bridles, which are usually formed of two pieces, each with shallow notches cut into them, are added, and embrace between them the shores, or struts, the whole being firmly connected with iron bolts.

The combinations used for the frames of centres will depend upon the position of the points of support and the size of the arches.

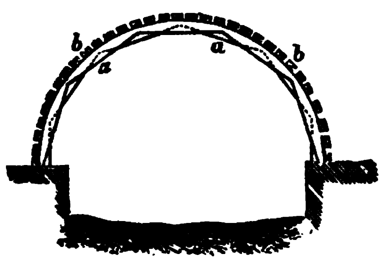


Fig. 80—Represents the rib of a centre for light arches.
a, a, rib formed as in Fig. 79.
b, b, bolster pieces which receive the masonry.

513. For small light arches (Fig. 80) the ribs may be formed

of two or more thicknesses of short boards, firmly nai ed together; the boards in each course abutting end to end by a joint in the direction of the radius of curvature of the arch, and breaking joints with those of the other course. The ribs are shaped to the form of the intrados of the arch, to receive the bolsters, which are of battens cut to suitable lengths and nailed to the ribs.

514. For heavy arches with wide spans, when firm intermediate points of support can be procured between the abutments, the back pieces (Fig. 81) may be supported by shores placed

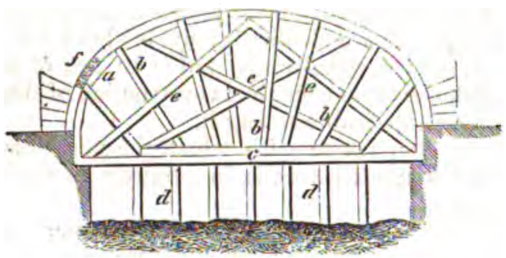


Fig. 81—Represents the rib of a centre with intermediate points of support.
a, back pieces of the rib which receive the bolsters *f*.
b, *b*, struts which support the back pieces.
e, *e*, braces.
c, solid beam resting on the intermediate supports *d*, *d*, which receive the ends of the struts *b*, *b*.

under the blocks in the direction of the radii of curvature of the arch, or of inclined struts (Fig. 82) resting on the points of

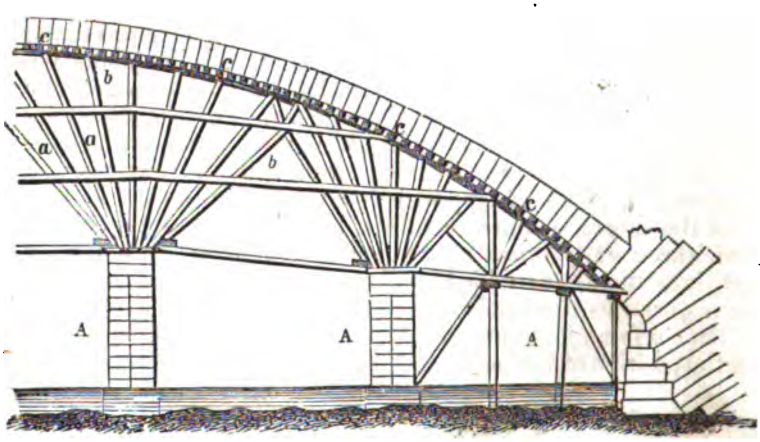


Fig. 82—Represents a part of the rib of Grosvenor Bridge over the Dee at Chester. Span 200 feet.
A, A, intermediate points of support.
a, *a*, *a*, struts resting upon cast iron sockets on the supports A.
b, *b*, two courses of plank each 4½ inches thick bent over the struts *a*, *a*, to the form of the arch, the courses breaking joints.
c, *c*, folding wedges laid upon the back pieces *b* of each rib to receive the bolsters on which the voussoirs are laid.

support. The shores, or struts, are prevented from bending by braces suitably placed for the purpose.

515. If intermediate points of support cannot be obtained, a broad framed support must be made at each abutment to receive the extremities of the struts that sustain the back pieces. The framed support (Fig. 83) consists of a heavy beam laid either

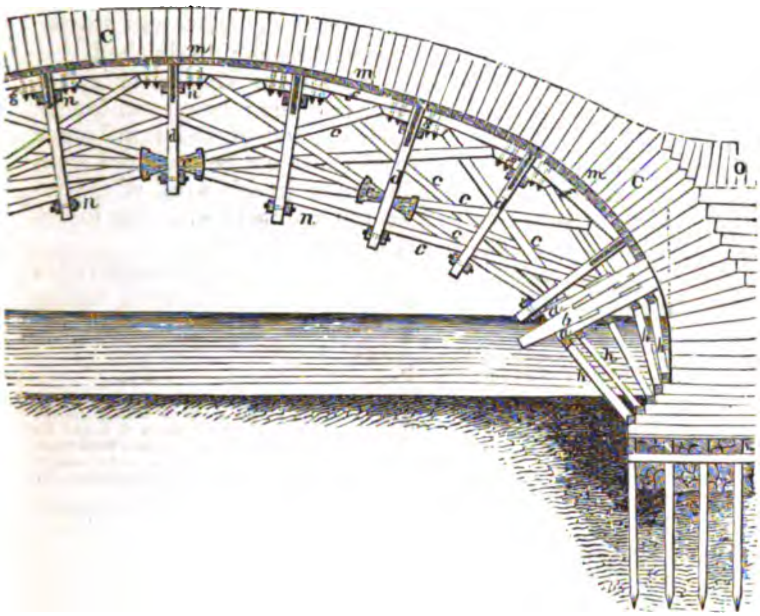


Fig. 83—Represents a part of a rib of Waterloo Bridge over the Thames.
a, a, and b, three heavy beams, forming the *striking plates*, which with the shores h, h, form the framed support for the struts of the centre.
c, c, struts abutting against the blocks g, g placed under the joints of the back pieces f, f.
d, d, bridle or radial pieces in pairs which are confined at top and bottom between the horizontal ties n, n of the ribs, also in pairs.
e, e, cast iron sockets.
m, m, bolsters of the centre resting on the back pieces f.

horizontally, or inclined, and is placed at that joint of the arch, (the one which makes an angle of about 30° with the horizon,) where the voussoirs, if unsupported beneath, would slide on their beds. This beam is borne by shores which find firm points of support on the foundations of the abutment.

The back pieces of the centre (Fig. 83) may be supported by inclined struts which rest immediately upon the framed support, one of the two struts under each block resting upon one of the framed supports, the other on the one on the opposite side, the two struts being so placed as to make equal angles with the radius of curvature of the arch drawn through the middle point of the block. Bridle pieces, placed in the direction of the radius of curvature, embrace the blocks and struts in the usual manner

and prevent the latter from sagging. This combination presents a figure of invariable form, as the strain at any one point is received by the struts and transmitted directly to the fixed points of support. It has the disadvantage of requiring beams of great length when the span of the arch is considerable, and of presenting frequent crossing of the struts where notches will be requisite, and the strength of the beams thereby diminished.

The centre of Waterloo Bridge over the Thames (Fig. 83) was framed on this principle. To avoid the inconveniences resulting from the crossing of the struts, and of building beams of sufficient length where the struts could not be procured from a single beam, the device was imagined in this work of receiving the ends of several struts at the points of crossing into a large cast-iron socket suspended by a bridle piece.

516. When the preceding combination cannot be employed, a strong truss, (Fig. 84,) consisting of two inclined struts resting

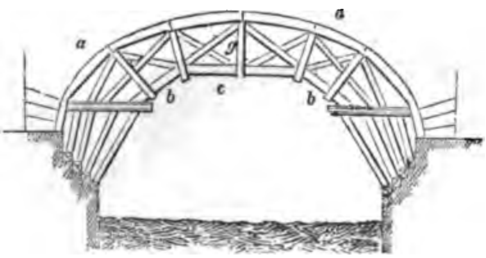


Fig. 84—Represents a frame for a rib in which the two inclined struts *b*, *b* and the straining beams *c* form intermediate supports for some of the struts that support the back pieces *a*, *a*. *e* and *d* are the framed extreme supports.

upon the framed supports, and abutting at top against a straining beam, may be formed to receive the ends of some of the struts which support the back pieces. This combination, and all of a like character, require that the arch should not be constructed more rapidly on one side of the centre than on the other, as any inequality of strain on the two halves of the centre would have a tendency to change the shape of the frame, thrusting it in the direction of the greater strain.

517. *Means used for striking Centres.* When the arch is completed the centres are detached from it, or struck. To effect this in large centres an arrangement of wedge blocks is used, termed the *striking plates*, by means of which the centre may be gradually lowered and detached from the soffit of the arch. This arrangement consists (Fig. 83) in forming steps upon the upper surface of the beam which forms the framed support to receive a wedge-shaped block, on which another beam, having its under surface also arranged with steps, rests. The struts of the rib either abut against the upper surface of the top beam, or else are inserted into cast-iron sockets, termed *shoe-plates*, fastened to

this surface. The centre is struck by driving back the wedge block.

518. When the struts rest upon intermediate supports between the abutments, double, or *folding* wedges may be placed under the struts, or else upon the back pieces of the ribs under each bolster. The latter arrangement presents the advantage of allowing any part of the centre to be eased from the soffit, instead of detaching the whole at once as in the other methods of striking wedges. This method was employed for the centres of Grosvenor Bridge, (Fig. 82,) over the river Dee at Chester, and was perfectly successful both in allowing a gradual settling of the arch at various points, and in the operation of striking.

519. *Ties and Braces for detached Frames.* When a series of frames concur to one end, as, for example, the main beams of a bridge, the trusses of a roof, ribs of a centre, &c., they require to be tied together and stiffened by other beams to prevent any displacement, and warping of the frames. For this purpose beams are placed in a horizontal position and notched upon each frame at suitable points to connect the whole together; while others are placed crossing each other, in a diagonal direction, between each pair of frames, with which they are united by suitable joints, to stiffen the frames and prevent them from yielding to any lateral effort. Both the ties and the diagonal braces may be either of single beams, or of beams in pairs, so arranged as to embrace between them the part of the frames with which they are connected.

520. *Joints.* The form and arrangement of joints will depend upon the relative position of the beams joined, and the object of the joint.

Joints may be required for various purposes, either to connect the ends of beams of which the axes are in the same right line, or make an angle between them; or the end of one beam with the face of another; or where the face of one beam rests upon that of another.

In all arrangements of joints, the axes of the beams connected should lie in the same plane in which the strain upon the frame acts; and the combination should be so arranged that the parts will accurately fit when the frame is put together, and that any portion may be displaced without disconnecting the rest. The simplest forms most suitable to the object in view will usually be found to be the best, as offering the most facility in obtaining an accurate fit of the parts.

In adjusting the surfaces of the joints an allowance should be made for any settling in the frame which may arise either from the shrinking of the timber in seasoning while in the frame, or from the fibres yielding to the action of the strain. This is done

by leaving sufficient play in the joints when the frame is first set up, to admit of the parts coming into perfect contact when the frame has attained its final settling. Joints formed of plane surfaces present more difficulty in this respect than curved joints, as the bearing surfaces in the latter case will remain in contact should any slight change take place in the relative positions of the beams from settling; whereas in the former a slight settling might cause the strains to be thrown upon a corner, or edge of the joint, by which the bearing surfaces might be crushed, and the parts of the frame work wrenched asunder from the leverage which such a circumstance might occasion.

The surface of a joint subjected to pressure should be as great as practicable, to secure the parts in contact from being crushed by the strain; and the surface should be perpendicular to the direction of the strain to prevent sliding.

A thin sheet of wrought iron, or lead, may be inserted between the surfaces of joints where, from the magnitude of the strain, one of them is liable to be crushed by the other, as in the case of the end of one beam resting upon the face of another.

521. Folding wedges, and pins, or *tree-nails*, of hard wood are used to bring the surfaces of joints firmly to their bearings, and retain the parts of the frame in their places. The wedges are inserted into square holes, and the pins into auger-holes made through the parts connected. As the object of these accessories is simply to bring the parts connected into close contact, they should be carefully driven in order not to cause a strain that might crush the fibres.

To secure joints subjected to a heavy strain, bolts, straps, and hoops of wrought iron are used. These should be placed in the best direction to counteract the strain and present the parts from separating; and wherever the bolts are requisite they should be inserted at those points which will least weaken the joint.

522. *Joints of Beams united end to end.* When the axes of the beams are in the same right line, the form of the joint will depend upon the direction of the strain. If the strain is one of compression, the ends of the beams may be united by a square joint perpendicular to their axes, the joint being secured (Fig. 85)

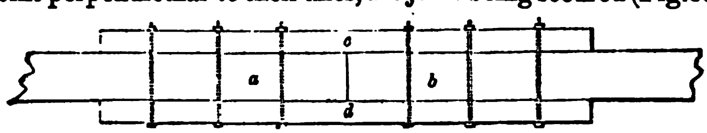


Fig. 85.—Represents the manner in which the end joint of two beams *a* and *b* is fished or secured by side pieces *c* and *d* bolted to them.

by four short pieces so placed as to embrace the ends of the beams, and being fastened to the beams and to each other by

bolts. This arrangement, termed *fishing a beam*, is used only for rough work. It may also be used when the strain is one of extension; in this case the short pieces (Fig. 86) may be notched

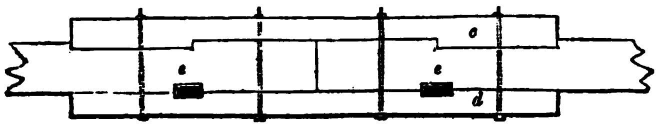


Fig. 86—Represents a fished joint in which the side pieces *c* and *d* are either let into the beams or secured by keys *e*, *e*.

upon the beams, or else keys of hard wood, inserted into shallow notches made in the beams and short pieces, may be employed to give additional security to the joint.

A joint termed a *scarf* may be used for either of the foregoing purposes. This joint may be formed either by halving the beams on each other near their ends, (Fig. 87,) and securing the joints

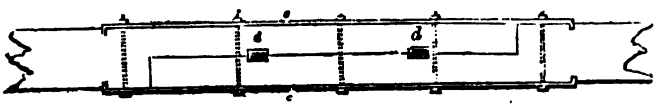


Fig. 87—Represents a scarf joint secured by iron plates *c*, *c*, keys *d*, *d*, and bolts.

by bolts, or straps; or else by so arranging the ends of the two beams that each shall fit into shallow triangular notches cut into the other, the joint being secured by iron hoops. This last method is employed for round timber.

523. When beams united at their ends are subjected to a cross strain, a scarf joint is generally used, the under part of the joint being secured by an iron plate confined to the beams by bolts. The scarf for this purpose may be formed simply by halving the beams near their ends; but a more usual and better form (Fig.

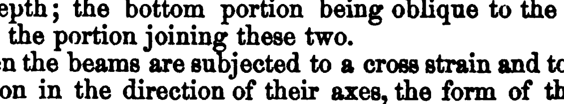


Fig. 88—Represents a scarf joint for a cross strain secured at bottom by a piece of timber *c* confined to the beams by iron hoops *d*, *d* and keys *e*, *e*.

88) is to make the portion of the joint at the top surface of the beams perpendicular to their axes, and about one third of their depth; the bottom portion being oblique to the axis, as well as the portion joining these two.

When the beams are subjected to a cross strain and to one of extension in the direction of their axes, the form of the scarf must be suitably arranged to resist each of these strains. The one shown in Fig. 89 is a suitable and usual form for these objects. A folding wedge key of hard wood is inserted into a space left

between the parts of the joint which catch when the beams are drawn apart. The key serves to bring the surfaces of the joints

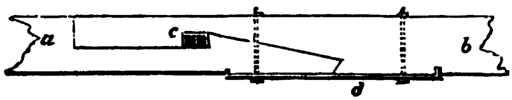


Fig. 89—Represents a scarf joint arranged to resist a cross strain and one of extension. The bottom of the joint is secured by an iron plate confined by bolts. The folding wedge key inserted at c serves to bring all the surfaces of the joints to their bearings.

to their bearings, and to form an abutting surface to resist the strain of extension. In this form of scarf the surface of the joint which abuts against the key will be compressed; the portions of the beams just above and below the key will be subjected to extension. These parts should present the same amount of resistance, or have an equality of cross section. The length of the scarf should be regulated by the resistance with which the timber employed resists detrusion compared with its resistance to compression and extension.

524. When the axes of beams form an angle between them, they may be connected at their ends either by halving them on each other, or by cutting a mortise in the centre of one beam at the end, and shaping the end of the other to fit into it.

525. *Joints for connecting the end of one beam with the face of another.* The joints used for this purpose are termed *mortise and tenon joints.* Their form will depend upon the angle between the axes of the beams. When the axes are perpendicular the mortise (Fig. 90) is cut into the face of the beam, and the end

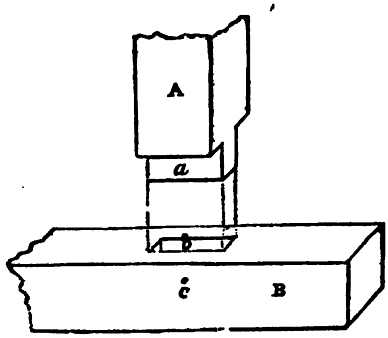


Fig. 90—Represents a mortise and tenon joint when the axes of the beams are perpendicular to each other.
a, tenon on the beam A.
b, mortise in the beam B.
c, pin to hold the parts together.

of the other beam is shaped into a tenon to fit the mortise. When the axes of the beams are oblique to each other, a triangular notch (Fig. 91) is usually cut into the face of one beam, the sides of the notch being perpendicular to each other, and a shallow mortise is cut into the lower surface of the notch; the end of the other beam is suitably shaped to fit the notch and mortise.

Tenon and mortise joints have received a variety of forms. The direction of the strain and the effect it may produce upon

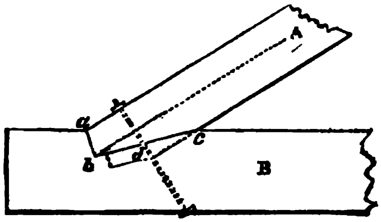


Fig. 91—Represents a mortise and tenon joint when the axes of the beams are oblique to each other. A notch whose surfaces *ab* and *bc* are at right angles is cut into the beam B and a shallow mortise *d* is cut below the surface *bc*. The end of the beam A is arranged to fit the notch and mortise in B. The joint is secured by a screw bolt.

the joint must in all cases regulate this point. In some cases the circular joint may be more suitable than those forms which are plane surfaces; in others a double tenon may be better than the simple joint.

526. *Tie joints.* These joints are used to connect beams which cross, or lie on each other. The simplest and strongest form of tie joint consists in cutting a notch in one, or both of the beams to connect them securely. But when the beams do not cross, but the end of one rests upon the other, a notch of a trapezoidal form (Fig. 92) may be cut in the lower beam to receive

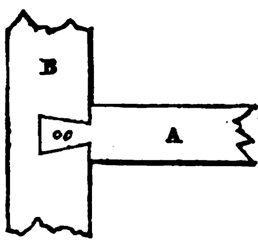


Fig. 92—Represents an ordinary dove-tail joint secured by a pin at *c*.

the end of the upper, which is suitably shaped to fit the notch. This, from its shape, is termed a *dove-tail joint.* It is of frequent use in joinery, but is not suitable for heavy frames where the joints are subjected to considerable strains, as it soon becomes loose from the shrinking of the timber.

527. *Iron Frames.* Cast and wrought iron are both used for frames. The former is most suitable where great strength combined with stiffness is required; the latter for light frames and wherever the strains act mainly as tensions.

In iron frames the same general principles of combination are applicable as in those of timber, and they admit of the same classification as frames of the latter material.

Cast iron is most easily wrought into the best forms for strength. The dimensions of the pieces must, however, be restricted within certain practical limits, both on account of the

labor and expense attendant upon the casting and handling of heavy pieces, and the difficulty of procuring them of uniform quality when of large size. In arranging the component parts of an iron frame, uniformity in the shape and dimensions is requisite both for economy and perfection of workmanship; and as far as practicable, the bulk of the different parts of each piece should be the same, in order to avoid the dangers arising from unequal shrinking in cooling.

Wrought iron may be hammered, or rolled into the most suitable form for strength, but for frames bars of a rectangular section are mostly used.

The joints in both cast and wrought iron frames are made upon the same principles as in those of timber, the forms being adapted to the nature of the material; they are secured by wrought iron wedges, keys, bolts, &c.

528. *Frames for Cross Strains.* Solid beams of cast iron, moulded into the most suitable forms for strength and for adaptation to the object in view, may be used for supporting a cross strain where the bearings are of a medium width. Solid wrought iron beams can be used with economy for the same purposes only for short bearings.

529. Open cast iron beams are seldom used except in combination with cast iron arches. Those of wrought iron are frequently used in structures. They may be formed of a top and bottom rail connected by diagonal pieces, forming the ordinary lattice arrangement; or a piece bent into a curved form may be placed

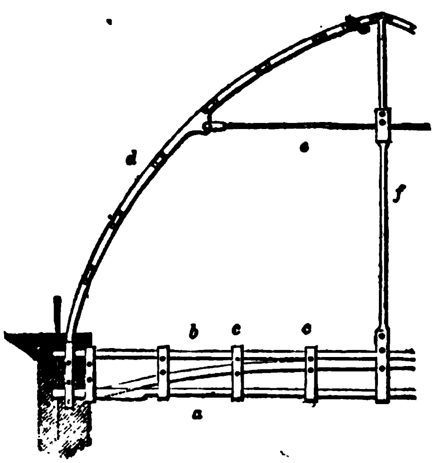


Fig. 93—Represents an open beam of wrought iron consisting of a top and bottom rail *a* and *b*, with an intermediate curved piece, the whole secured by the pieces *c*, *c* in pairs bolted to them.
d, *e*, and *f* represent the parts of a truss of a curved light roof, connected with the open beam; and also the manner in which the whole are secured to the wall.

between the rails, or any other suitable combination (Fig. 93) may be used which combines lightness with strength and stiffness.

530. *Iron Arches.* Cast iron arches may be used for the same objects as those of timber. The frames for these purposes consist of several parallel ribs of uniform dimensions which are cast into an arch form, the ribs being connected by horizontal ties, and stiffened by diagonal braces. The weight of the superstructure is transmitted to the curved ribs in a variety of ways; most usually by an open cast iron beam, the lower part of which is so shaped as to rest upon the curved rib, and the upper part suitably formed for the object in view. These beams are also connected by ties, and stiffened by diagonal braces.

Each rib, except for narrow spans, is composed of several pieces, or segments, between each pair of which there is a joint in the direction of the radius of curvature. The forms and dimensions of the segments are uniform. The segments are usually either solid, (Fig. 94,) or open plates of uniform thickness, having

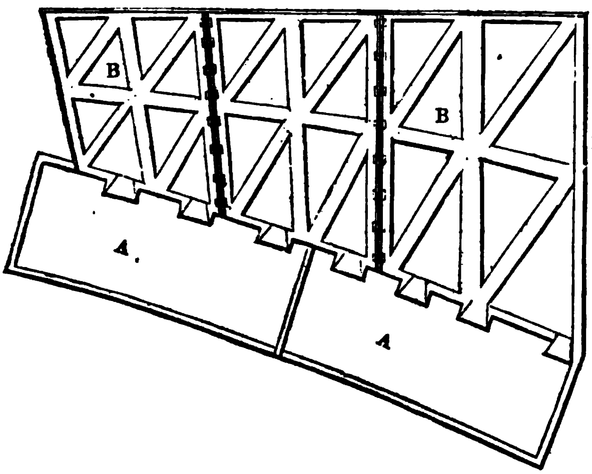


Fig. 94 — Represents a portion of a cast iron plate arch with an open cast iron beam.
A, A, segments of the arch.
B, B, panels of the open beam connected at the joints *ab*.

a flanch of uniform breadth and depth at each end, and on the entrados and intrados. The flanch serves both to give strength to the segment and to form the connection between the segments and the parts which rest upon the rib.

The ribs are connected by tie plates which are inserted between the joints of the segments, and are fastened to the segments by iron screw bolts which pass through the end flanches of the segments and the tie plate between them. The tie plates may be either open, or solid; the former being usually preferred on account of this superior lightness and cheapness.

The frame work of the ribs is stiffened by diagonal pieces which are connected either with the ribs, or the tie plates. The diagonal braces are cast in one piece, the arms being ribbed, or

feathered, and tapering from the centre towards the ends in a suitable manner to give lightness combined with strength.

The open beams (Fig. 94) which rest upon the curved ribs are cast in a suitable number of panels; the joint between each pair being either in the direction of the radii of the arch, or else vertical. These pieces are also cast with flanches, by which they are connected together and with the other parts of the frame. The beams, like the ribs, are tied together and stiffened by ties and diagonal braces.

Beams of suitable forms for the purposes of the structure are placed either lengthwise, or crosswise upon the open beams.

531. Curved ribs of a tubular form have, within a few years back, been tried with success, and bid fair to supersede the ordinary plate rib, as with the same amount of metal they combine more strength than the flat rib.

The application of tubular ribs was first made in the United

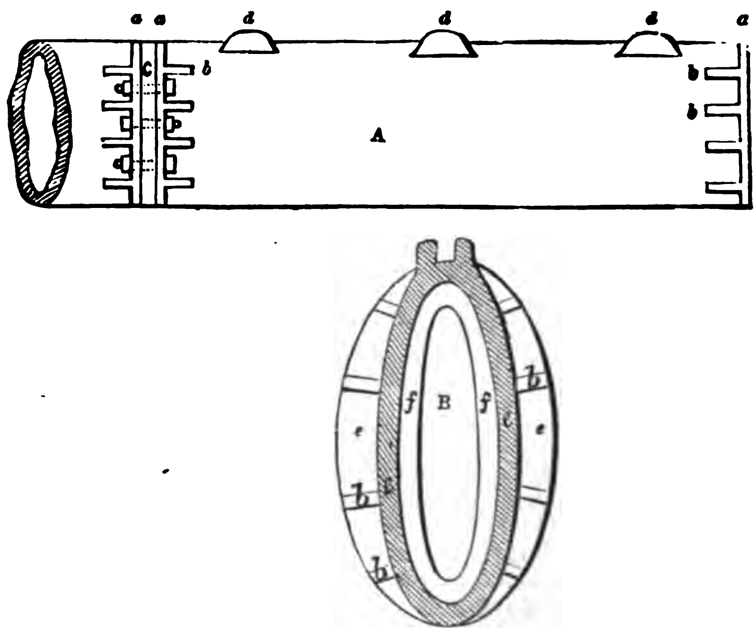


Fig. 90—Represents a side view A, and a cross section and end view B through a saddle piece of the tubular arch of Major Delafield.

a, *a*, (Fig A) a side view, and (Fig. B) an end view of the elliptical flanches of the end of each segment.

b, *b*, shoulders, or ribs to strengthen the flanches against lateral strains.

c, tie plate between the ribs.

f, (Fig. B) side view of the rim of the tie-plate fitted to the interior of the tube.

d, *d*, (Figs. A and B) saddle pieces to receive the open beams of a form similar to Fig 94, which rest on the tubular ribs.

e, cross section of the rib through the saddle piece.

States by Major Delafield of the U. S. Corps of Engineers, in an arch for a bridge of 80 feet span. Each rib was formed of nine segments; each segment (Fig. 95) being cast in one piece, the cross section of which is an elliptical ring of uniform thickness, the transverse axis of the ellipse being in the direction of the radius of curvature of the rib. A broad elliptical flanch with ribs, or stays, is cast on each end of the segment, to connect the parts with each other; and three *chairs*, or *saddle pieces*, with grooves in them, are cast upon the entrados of each segment, and at equal intervals apart, to receive the open beam which rests on the curved rib.

The ribs are connected by an open tie plate, (Fig. 95.) Raised elliptical projections are cast on each face of the tie plate, where it is connected with the segments, which are adjusted accurately to the interior surface of each pair of segments, between which the tie plate is embraced. The segments and plate are fastened by screw bolts passed through the end flanches of the segments.

The tie plates form the only connection between the curved ribs; the broad ribbed flanches of the segments, and the raised rims of the tie plates inserted into the ends of the tubes, giving all the advantages and stiffness of diagonal pieces.

532. Tubular ribs with an elliptical cross section have been used in France for many of their bridges. They were first introduced but a few years back by M. Polonceau, after whose

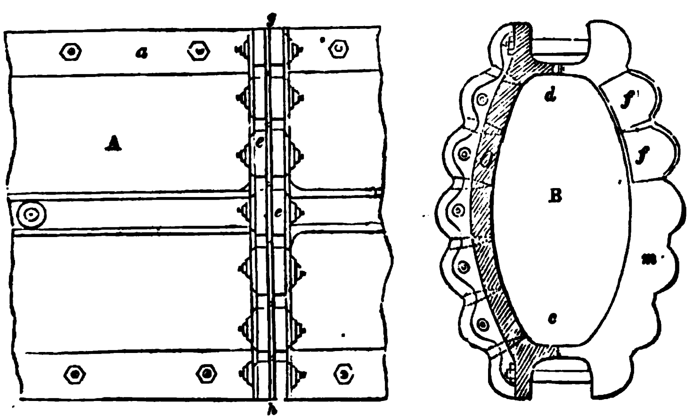


Fig. 96—Represents a side view A and a cross section and end view B through a joint of M. Polonceau's tubular arch.
a, *a*, top flanch, *b*, *b* bottom flanch of the semi-segments united along the vertical joint *cd* through the axis of the rib.
gh, side view of the joint between the flanches *e*, *e* of two semi-segments
m, inner side of the flanches.
c, cross section of a semi-segment and top and bottom flanches.
f, *f*, thin wedges of wrought iron placed between the end flanches of the semi-segments to bring the parts to their proper bearing.

designs the greater part of these structures have beer built. According to M. Polonceau's plan, each rib consists of two symmetrical parts divided lengthwise by a vertical joint Each half of the rib is composed of a number of segments so distributed as to break joints, in order that when the segments are put together there shall be no continuous cross joint through the ribs.

The segments (Fig. 96) are cast with a top and bottom flanch and one also at each end. The halves of the rib are connected by bolts through the upper and lower flanches, and the segments by bolts through the end flanches.

For the purposes of adjusting the segments and bringing the rib to a suitable degree of tension, flat pieces of wrought iron of a wedge shape are driven into the joints between the segments, and are confined in the joints by the bolts which fasten the segments and which also pass through these wedges.

To connect the ribs with each other, iron tubular pieces are

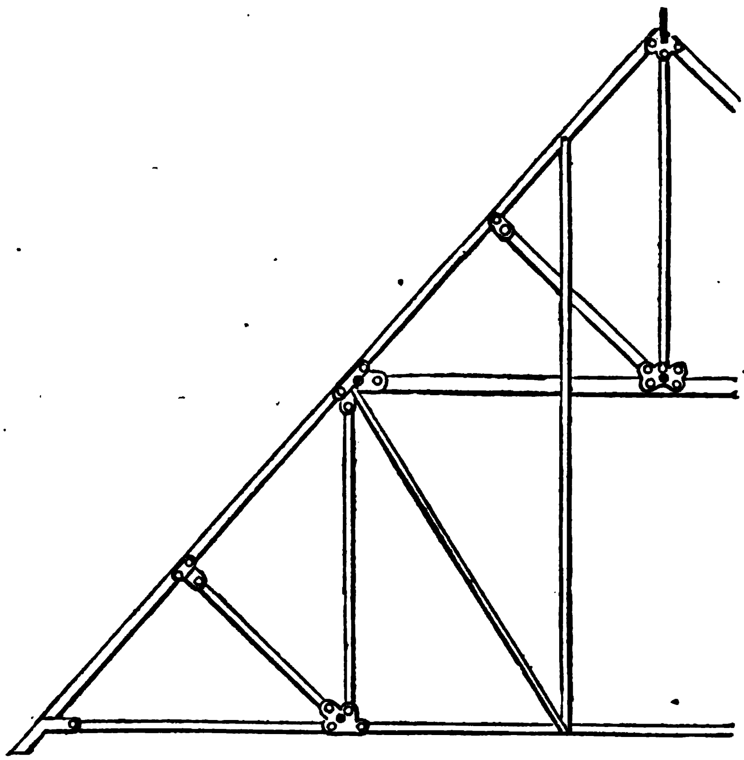


Fig. 97—Represents the half of a truss of wrought iron for the new Houses of Parliament, England. The pieces of this truss are formed of bars of a rectangular section. The joints are secured by cast iron sockets, within which the ends of the bars are secured by screw bolts.

placed between them, the ends of the tubes being suitably adjusted to the sides of the ribs. Wrought iron rods which serve as ties pass through the tubes and ribs, being arranged with screws and nuts to draw the ribs firmly against the tubular pieces. Diagonal pieces of a suitable form are placed between the ribs to give them the requisite degree of stiffness.

In the bridges constructed by Mr. Polonceau according to this plan, he supports the longitudinal beams of the roadway by cast iron rings which are fastened to the ribs and to each other, and bear a chair of suitable form to receive the beams.

533. *Iron roof Trusses.* Frames of iron for roofs have been made either entirely of wrought iron, or of a combination of wrought and cast iron, or of these two last materials combined with timber. The combinations for the trusses of roofs of iron are in all respects the same as in those for timber trusses. The parts of the truss subjected to a cross strain, or to one of com

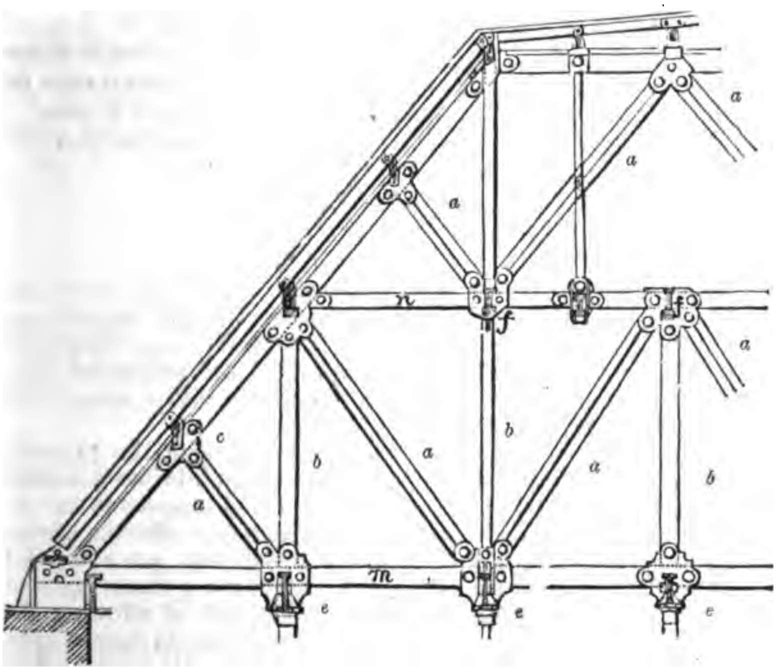


Fig. 98—Represents the half of a truss for the same building composed of wrought and cast iron.
a, a, feathered struts of cast iron.
b, b, suspension bars in pairs.
m, n, tie and straining bars.
e, e, and f, f, cross sections of beams resting in the cast iron sockets connected with the suspension bars.

pression, are arranged to give the most suitable forms for strength, and to adapt them to the object in view. The parts subjected to a strain of extension, as the tie-beam and king and queen posts, are made either of wrought iron or of timber, as may be found best adapted to the particular end proposed. The joints are in some cases arranged by inserting the ends of the beams, or bars, in cast iron sockets, or shoes of a suitable form; in others the beams are united by joints arranged like those for timber frames, the joints in all cases being secured by wrought iron bolts and keys. (Figs. 97, 98, and 99.)

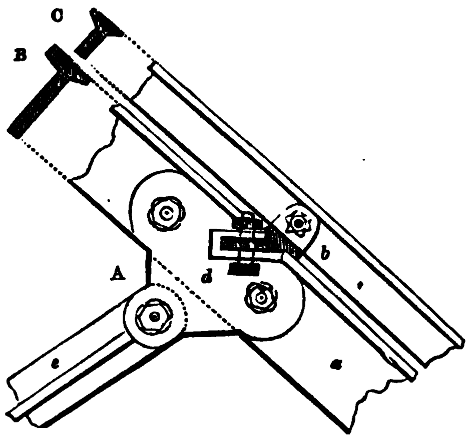


Fig. 99—Represents the arrangements of the parts at the join c in Fig. 98.
A, side view of the pieces and joint.
a, principal rafter of the cross section B.
b, common rafter of the cross section C.
c, cross section of purlins and joint for fastening the common rafters to the purlins.
d, cast iron socket arranged to confine the pieces a, b c, e.

534. *Flexible Supports for Frames.* Chains and ropes may frequently be substituted with advantage, for rigid materials, as intermediate points of support for frames, forming systems of suspension in which the parts supported are suspended from the flexible supports, or else rest upon them either directly, or through the intermedium of rigid beams.

535. All systems of suspension are based upon the property which the catenary curve in a state of equilibrium possesses of converting vertical pressures upon it into tensions in the direction of the curve. These systems therefore offer the advantages of presenting the materials of which they are composed in the best manner for calling into action the greatest amount of resistance of which they are capable, and of allowing the dimensions of the parts to be adapted to the strain thrown upon them more accurately than can be done in rigid systems; thus avoiding much of the unproductive weight necessarily introduced into structures of stone, wood, and cast iron. They offer also the farther advantages that in their construction the parts of which they are composed can be readily adjusted, put together,

ard taken apart for repairs. They present the disadvantages of changing both their form and dimensions from the action of the weather and variations of temperature, and of being liable to grave accidents from undulations and vertical vibrations caused by high winds, or moveable loads. The require, therefore, that the fixed points of support of the system should be very firm and durable, and that constant attention should be given to keep the system in a thorough state of repair.

536. A chain or rope, when fastened at each extremity to fixed points of support, will, from the action of gravity, assume the form of a catenary in a state of equilibrium, whether the two extremities be on the same, or different levels. The relative height of the fixed supports may therefore be made to conform to the locality.

537. The ratio of the versed sine of the arc to its chord, or span, will also depend, for the most part, on local circumstances and the object of the suspended structure. The wider the span, or chord, for the same versed sine, the greater will be the tension along the curve, and the more strength will therefore be required in all the parts. The reverse will obtain for an increase of versed sine for the same span; but there will be an increase in the length of the curve.

538. The chains may either be attached at the extremities of the curve to the fixed supports, or piers; or they may rest upon them, (Fig. 100, 101,) being fixed into anchoring masses, or

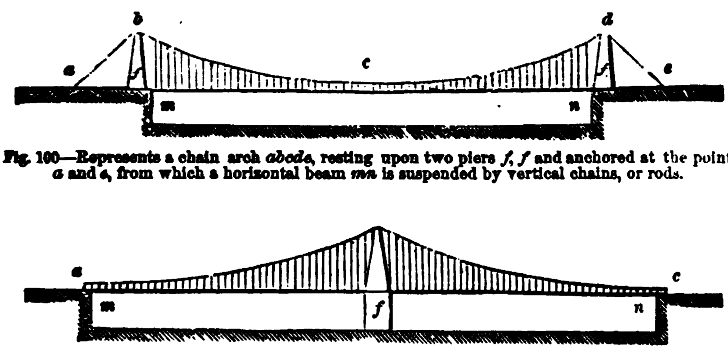


Fig. 100—Represents a chain arch *abcde*, resting upon two piers *f*, *f* and anchored at the points *a* and *e*, from which a horizontal beam *mn* is suspended by vertical chains, or rods.

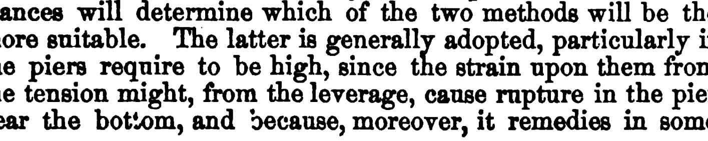


Fig. 101—Represents the manner in which the system may be arranged when a single pier is placed between the extreme points of the bearing.

abutments, at some distance beyond the piers. Local circumstances will determine which of the two methods will be the more suitable. The latter is generally adopted, particularly if the piers require to be high, since the strain upon them from the tension might, from the leverage, cause rupture in the pier near the bottom, and because, moreover, it remedies in some

degree the inconveniences arising from variations of tension caused either by a moveable load, or changes of temperature. Piers of wood, or of cast iron moveable around a joint at their base, have been used instead of fixed piers, with the object of remedying the same inconveniences.

539. When the chains pass over the piers and are anchored at some distance beyond them, they may either rest upon saddle pieces of cast iron, or upon pulleys placed on the piers.

540. The position of the anchoring points will depend upon local circumstances. The two branches of the chain may either make equal angles with the axis of the pier, thus assuming the same curvature on each side of it, or else the extremity of the chain may be anchored at a point nearer to the base of the pier. In the former case the resultant of the tensions and weights will be vertical and in the direction of the axis of the pier, in the latter it will be oblique to the axis, and should pass so far within the base that the material will be secure from crushing.

541. The anchoring points are usually masses of masonry of a suitable form to resist the strain to which they are subjected. They may be placed either above or below the surface of the ground, as the locality may demand. The kind of resistance offered by them to the tension on the chain will depend upon the position of the chain. If the two branches of the chain make equal angles with the axis of the pier, the resistance offered by the abutments will mainly depend upon the strength of the material of which they are formed. If the branches of the chain make unequal angles with the axis of the pier, the branch fixed to the anchoring mass is usually deflected in a vertical direction, and so secured that the weight of the abutment may act in resisting the tension on the chain. In this plan fixed pulleys placed on very firm supports will be required at the point of deflection of the chain to resist the pressure arising from the tension at these points.

Whenever it is practicable the abutment and pier should be suitably connected to increase the resistance offered by the former.

The connection between the chains and abutments should be so arranged that the parts can be readily examined. The chains at these points are sometimes imbedded in a paste of fat lime to preserve them from oxidation.

542. The chains may be placed either above or below the structure to be supported. The former gives a system of more stability than the latter, owing to the position of the centre of gravity, but it usually requires high piers, and the chain cannot generally be so well arranged as in the latter to subserve the required purposes. The curves may consist of one or more chains. Several are usually preferred to a single one, as for the same

amount of metal they offer more resistance, can be more accurately manufactured, are less liable to accidents, and can be more easily put up and replaced than a single chain. The chains of the curve may be placed either side by side, or above each other, according to circumstances.

543. The curves may be formed either of chains, of wire cables, or of bands of hoop iron. Each of these methods has found its respective advocates among engineers. Those who prefer wire cables to chains urge that the latter are more liable to accidents than the former, that their strength is less uniform and less in proportion to their weight than that of wire cables, that iron bars are more liable to contain concealed defects than wire, that the proofs to which chains are subjected may increase without, in all cases, exposing these defects, and that the construction and putting up of chains is more expensive and difficult than for wire cables. The opponents of wire cables state that they are open to the same objections as those urged against chains, that they offer a greater amount of surface to oxidation than the same volume of bar iron would, and that no precaution can prevent the moisture from penetrating into a wire cable and causing rapid oxidation.

That in this, as in all like discussions, an exaggerated degree of importance should have been attached to the objections urged on each side was but natural. Experience, however, derived from existing works, has shown that each method may be applied with safety to structures of the boldest character, and that wherever failures have been met with in either method, they were attributable to those faults of workmanship, or to defects in the material used, which can hardly be anticipated and avoided in any novel application of a like character. Time alone can definitively decide upon the comparative merits of the two methods, and how far either of them may be used with advantage in the place of structures of more rigid materials.

544. The chains of the curves may be formed of either round, square, or flat bars. Chains of flat bars have been most generally used. These are formed in long links which are connected by short plates and bolts. Each link consists of several bars of the same length, each of which is perforated with a hole at each end to receive the connecting bolts. The bars of each link are placed side by side, and the links are connected by the plates which form a short link, and the bolts.

The links of the portions of the chain which rest upon the piers may either be bent, or else be made shorter than the others to accommodate the chain to the curved form of the surface on which it rests.

545. The vertical suspension bars may be either of round or

square bars. They are usually made with one or more articulations, to admit of their yielding with less strain to the bar to any motion of vibration, or of oscillation. They may be suspended from the connecting bolts of the links, but the preferable method is to attach them to a suitable saddle piece which is fitted to the top of the chain and thus distributes the strain upon the bar more uniformly over the bolts and links. The lower end of the bar is suitably arranged to connect it with the part suspended from it.

546. The wire cables used for curves are composed of wires laid side by side, which are brought to a cylindrical shape and confined by a spiral wrapping of wire. To form the cable several equal sized ropes, or yarns, are first made. This may be done by cutting all the wires of the length required for the yarn, or by uniting end to end the requisite number of wires for the yarn, and then winding them around two pieces of wrought or of cast iron, of a horse-shoe shape, with a suitable gorge to receive the wires, which are placed as far asunder as the required length of the yarn. The yarn is firmly attached at its two ends to the iron pieces, or *cruppers*, and the wires are temporarily confined at intermediate points by a spiral lashing of wire. Whichever of the two methods be adopted, great care must be taken to give to every wire of the yarn the same degree of tension by a suitable mechanism. The cable is completed after the yarns are placed upon the piers and secured to the anchoring ropes or chains; for this purpose the temporary lashings of the yarns are undone, and all the yarns are united and brought to a cylindrical shape and secured throughout the extent of the cable, to within a short distance of each pier, by a continuous spiral lashing of wire.

The part of the cable which rests upon the pier is not bound with wire, but is spread over the saddle piece with a uniform thickness.

547. The suspension ropes are formed in the same way as the cables; they are usually arranged with a loop at each end, formed around an iron crupper, to connect them with the cables, to which they are attached, and to the parts of the structure suspended from them by suitable saddle pieces.

548. To secure the cables from oxidation the iron wires are coated with varnish before they are made into yarns, and after the cables are completed they are either coated with the usual paints for securing iron from the effects of moisture, or else covered with some impermeable material.

549. *Experiments on the Strength of Frames.* Experimental researches on this point have been mostly restricted to those made with models on a comparatively small scale, owing to the expense and difficulty attendant upon experiments on frames

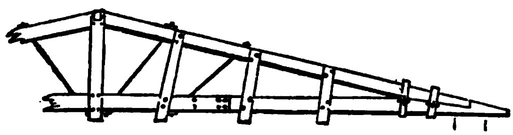
having the form and dimensions of those employed in ordinary structures.

Among the most remarkable experiments on a large scale are those made by order of the French government at Lorient, under the direction of M. Riebell, the superintending engineer of the port, and published in the *Annales Maritimes et Coloniales*, Feb. and Nov., 1837.

The experiments were made by first setting up the frame to be tried, and, after it had settled under the action of its own weight, suspending from the back of it, by ropes placed at equal intervals apart, equal weights to represent a load uniformly distributed over the back of the frame.

The results contained in the following table are from experiments on a truss (Fig. 102) for the roof of a ship shed. The truss consisted of two rafters and a tie beam, with suspension

Fig. 102.



pieces in pairs, and diagonal iron bolts which were added because it was necessary to scarf the tie beam. The span of the truss was 65½ feet; the rafters had a slope of 1 perpendicular to 4 base. The thickness of the beams, measured horizontally, was about 2½ inches, their depth about 18 inches. The amount of the settling at each rope was ascertained by fixed graduated vertical rods, the measures being taken below a horizontal line marked 0.

WEIGHTS BORNE BY THE TRUSS.	Amount of settling on the right of the ridge below the horizontal 0, in inches.				
	At 18 inches from the ridge.	At 4 ft. 6 in. from the ridge.	At 8 ft. from the ridge.	At 10 ft. from the ridge.	At 15 ft. from the ridge.
Weight uniformly distributed, 1654 lbs. . . .	0.15	0.15	0.15	0.15	0.15
Do. do. 8680 lbs. . . .	1.6	1.7	1.9	1.8	1.1
Do. do. 1654 lbs. and 1868 lbs., suspended from the centre of the frame . . .	0.4	0.5	0.4	0.8	0.2
8660 lbs., uniformly distributed, and 1868 lbs. from the centre	2.0	2.1	2.3	2.1	1.2

The following table gives the results of experiments made on frames of the usual forms of straight and curved timber for roof trusses. The curved pieces were made of two thicknesses, each

$3\frac{1}{2}$ inches. The numbers in the fifth column give the ratios between the weight of the frame and that of the weight borne by which the elasticity was not impaired.

Fig. 103.

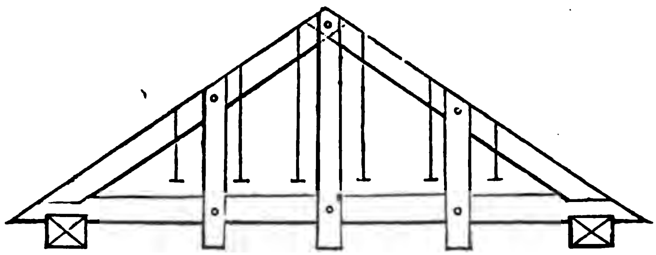


Fig. 104.

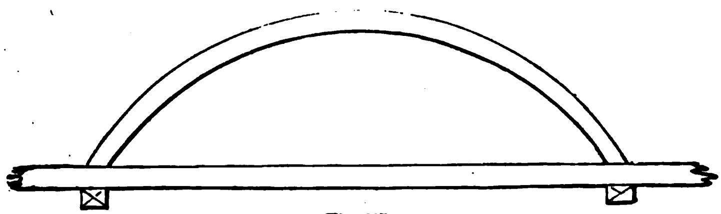


Fig. 105.

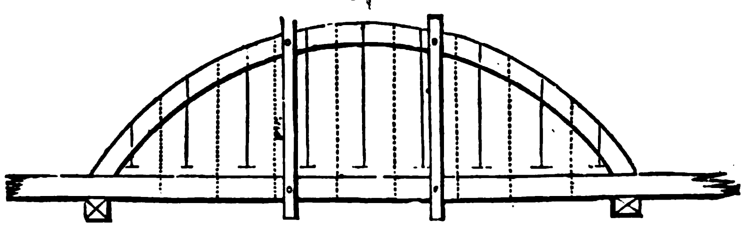
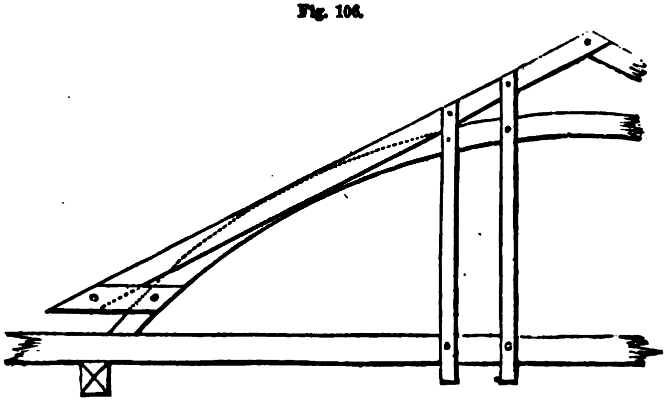


Fig. 106.



DESCRIPTION OF THE FRAMES.	Span, or bearing.	Rise, or versed sine.	Depth of beams.	Horizontal breadth of beams.	Ratios between weight in lbs. of frame, and that of the load borne.	Weight borne without impairing elasticity of the wood.	Weight by which the elasticity was visibly changed.
Frame formed of two rafters and a tie beam .	25 ft.	8 ft.	8,5 in.	8,1 in.	14,80	9600	8916
Do. do. do. and suspension pieces in pairs, (Fig. 103). .	—	—	—	—	8.88	2770	5590
Frame of a segment arch confined by a tie beam, (Fig. 104)	54 ft.	11 ft.	13 in.	7 in.	8.85	6580	12840
Do. do. do. with suspension pieces in pairs, (Fig. 105) .	—	—	—	—	2.88	9500	18077
Frame of a segment arch with rafters confined at their foot by a tie piece, (Fig. 106) .	—	—	—	—	8.91	6111	21896
Frame of a full centre arch confined by a tie beam	50 ft.	25 ft.	—	—	1.00	4886	5161
Do. do. do. with suspension pieces in pairs	—	—	—	—	0.91	7898	8158

See Note A, Appendix.

BRIDGES, &c.

550. UNDER this head will be comprised that class of structures whose object is to afford a line of communication above the general surface of a country, either by means of a roadway, or of a water-way, without obstructing those communications which lie upon the surface.

When the structure supports a roadway it is termed a *viaduct*; and when a water-way an *aqueduct*.

If the structure is limited to affording a communication over a water-course, it is termed a *bridge* when it supports a roadway, and an *aqueduct-bridge* when it affords a water-way.

For the convenience of description, bridges, &c., may be classified either from the kind of material of which they are constructed, as a *Stone-Bridge*, a *Wooden-Bridge*, &c., or from the character of the structure, as a *Permanent-Bridge*, a *Draw-Bridge*, &c.

STONE BRIDGES.

551. A stone bridge consists of a roadway which rests upon one or more arches, usually of a cylindrical form, the abutments and piers of the arches being of sufficient height and strength to secure them and the roadway from the effects of an extraordinary rise in the water-course.

552. *Locality*. The point where a bridge may be required, as well as the direction of the *axis*, or centre line of the roadway over the bridge, usually depends upon the position of a line of communication which traverses the water-course, and of which the bridge is a necessary link. When, however, the engineer is not restricted in the choice of a suitable locality by this condition, he should endeavor to select one where the soil of the bed will afford a firm support for the foundations of the structure: where the *approaches*, or avenues leading from the banks of the watercourse to the bridge can be easily made, not requiring high embankments or deep excavations; and one where the regimen of the water-course is uniform and not likely to be changed in any hurtful degree by elbows, or other variations in the water-way near the bridge, or by the obstruction which the foundations, &c., of the structure may offer to the free discharge of the water.

To avoid the difficulties which the construction of askew arches

presents, the axis of the bridge should be perpendicular to the direction of the thread of the current, since for the security of the foundations, the faces of the piers and abutments of the arches must be placed parallel to the thread of the current.

553. *Survey.* With whatever considerations the locality may have been selected, a careful survey must be made not only of it, but also of the water-course and its environs for some distance above and below the point which the bridge will occupy, to enable the engineer to judge of the probable effects which the bridge when erected may have upon the natural regimen of the water-course.

The object of the survey will be to ascertain thoroughly the natural features of the surface, the nature of the subsoil of the bed and banks of the water-course, and the character of the water-course at its different phases of high and low water, and of freshets. This information will be embodied in a topographical map; in cross and longitudinal sections of the water-course and the substrata of its bed and banks, as ascertained by soundings and borings; and in a descriptive memoir which, besides the usual state of the water-course, should exhibit an account of its changes, occasioned either by permanent or by accidental causes, as from the effects of extraordinary freshets, or from the construction of bridges, dams, and other artificial changes either in the bed or banks.

554. Having obtained a thorough knowledge both of the position to be occupied by the bridge and its environs, the two most essential points which will next demand the consideration of the engineer will be, in the first place, so to adapt his proposed structure to the locality, that a sufficient water-way shall be left both for navigable purposes and for the free discharge of the water accumulated during high freshets; and, in the second, to adopt such a system of foundations as will be most likely to ensure the safety of the structure when exposed to this cause of danger.

555. *Water-way.* When the natural water-way of a river is obstructed by any artificial means, the contraction, if considerable, will cause the water, above the point where the obstruction is placed, to rise higher than the level of that below it, and produce a fall, with an increased velocity due to it, in the current between the two levels. These causes during heavy freshets, may be productive of serious injury to agriculture, from the overflowing of the banks of the water course;—may endanger, if not entirely suspend navigation, during the seasons of freshets;—and expose any structure which, like a bridge, forms the obstruction, to ruin, from the increased action of the current upon the soil around its foundations. If, on the contrary, the natural water-way is enlarged at the point where the structure is placed, with

the view of preventing these consequences, the velocity of the current, during the ordinary stages of the water, will be decreased, and this will occasion deposits to be formed at the point, which, by gradually filling up the bed, might, on a sudden rise of the water, prove a more serious obstruction than the structure itself; particularly if the main body of the water should happen to be diverted by the deposit from its ordinary channels, and form new ones of greater depth around the foundations of the structure.

The water-way left by the structure should, for the reasons above, be so regulated that no considerable change shall be occasioned in the velocity of the current through it during the most unfavorable stages of the water.

556. For the purpose of deciding upon the most suitable velocity for the current through the contracted water-way formed by the structure, the velocity of the current and its effects upon the soil of the banks and bed of the natural water-way should be carefully noted at those seasons when the water is highest; selecting, in preference, for these observations, those points above and below the one which the bridge is to occupy, where the natural water-way is most contracted.

557. The velocity of the current at any point may be ascertained by the simple process of allowing a light ball, or *float* of some material, like white wax, or camphor, whose specific gravity is somewhat less than that of water, to be carried along by the current of the middle thread of the water-course, and noting the time of its passage between two fixed stations.

558. From the velocity at the surface, ascertained in this way, the average, or *mean velocity* of the water, which flows through the cross-section of any water-way between the stations where the observations are taken, may be found, by taking four fifths of the velocity at the surface.

Having the mean velocity of the natural water-way, that of the artificial water-way will be obtained from the following expression,

$$v = m \frac{\mathrm{s}}{s} \mathrm{v},$$

in which s and v represent, respectively, the area and mean velocity of the artificial water-way; s and v, the same data of the natural water-way; and m a constant quantity, which, as determined from various experiments, may be represented by the mixed number 1,097.

With regard to the effect of the increased velocity on the bed, there are no experiments which directly apply to the cases usually met with. The following table is drawn up from experiments

made in a confined channel, the bottom and sides of the channel being formed of rough boards.

Stages of accumulation termed	Velocity of river in feet per second.	Nature of the bottom which just bears such velocities.	Specific gravity of the material.
Ordinary floods.	3.2	Angular stones, the size of a hen's egg	2.25
	2.17	Rounded pebbles one inch in diameter	2.614
	1.07	Gravel of the size of garden beans	2.545
Uniform tenors.	0.62	Gravel of the size of peas	2.545
	0.71	Coarse yellow sand	2.36
Gliding	0.351	Sand, the grains the size of aniseeds	2.545
Dull	0.26	Brown potter's clay	2.64

559. *Bays*. With the data now before him, the engineer can proceed to the arrangement of the forms and details of the various parts of the proposed structure.

The first point to be considered under this head will be the number of *bays*, or intervals into which the natural water-way must be divided, and the forms and dimensions of the arches which span the bays.

As a general rule, there should be an odd number of bays, whenever the width of the water-way is too great to be spanned by a single arch. Local circumstances may require a departure from this canon; but when departed from, it will be at the cost of architectural effect; since no secondary feature can occupy the central point in any architectural composition without impairing the beauty of the structure to the eye; and as the arches are the main features of a stone bridge, the central point ought to be occupied by one of them.

The width of the bays will depend mainly upon the character of the current, the nature of the soil upon which the foundations rest, and the kind of material that can be obtained for the masonry.

For streams with a gentle current, which are not subject to heavy freshets, narrow bays, or those of a medium size may be adopted, because, even a considerable diminution of the natural water-way will not greatly affect the velocity under the bridge, and the foundations therefore will not be liable to be undermined. The difficulty, moreover, of laying the foundations in streams of this character is generally inconsiderable. For streams with a rapid current, and which are moreover subject to great freshets, wide bays will be most suitable, in order, by procuring a wide water-way, to diminish the danger to the points of support, in placing as few in the stream as practicable.

If materials of the best quality can be procured for the structure, wide bays with bold arches can be adopted with safety; but, if the materials are of an inferior quality, it will be most

prudent to adopt bays of a small, or medium space, and a strong form of arch.

560. *Arches.* Cylindrical arches with any of the usual forms of curve of intrados may be used for bridges. The selection will be restricted by the width of the bay, the highest water-level during freshets, the approaches to the bridge, and the architectural effect which may be produced by the structure, as it is more or less exposed to view at the intermediate stages between high and low water.

Oval and segment arches are mostly preferred to the full centre arch, particularly for medium and wide bays, for the reasons that, for the same level of roadway, they afford a more ample water-way under them, and their heads and spandrels offer a smaller surface to the pressure of the water during freshets than the full centre arch under like circumstances.

The full centre arch, from the intrinsic beauty of its form, the simplicity of its construction, and its strength, should be preferred to any other arch for bridges over water-courses of a uniformly moderate current, and which are not subjected to considerable changes in their water-levels, particularly when its adoption does not demand expensive embankments for the approaches.

If the bays spanned by the arches are of the same width, the curves of all the arches must be identical. If the bays are of unequal width, the widest should occupy the centre of the structure, and those on each side of the centre should either be of equal width, or else decrease uniformly from the centre to each extremity of the bridge. In this case the curves of the arches should be similar, and have their springing lines on the same level throughout the bridge.

The level of the springing lines will depend upon the rise of the arches, and the height of their crowns above the water-level of the highest freshets. The crown of the arches should not, as a general rule, be less than three feet above the highest known water-level, in order that a passage-way may be left for floating bodies descending during freshets. Between this, the lowest position of the crown, and any other, the rise should be so chosen that the approaches, on the one hand, may not be unnecessarily raised, nor, on the other, the springing lines be placed so low as to mar the architectural effect of the structure during the ordinary stages of the water.

When the arches are of the same size, the axis of the roadway and the principal architectural lines which run lengthwise along the heads of the bridge, as the top of the parapet, the cornice, &c., &c., will be horizontal, and the bridge, to use a common expression, be on a *dead level* throughout. This has for some time been a favorite feature in bridge architecture, few of the

more recent and celebrated bridges being without it, as it is thought to give a character of lightness and boldness to the structure which is wanting in bridges built with a uniform declivity from the centre to the extreme arches. Without stopping to examine this claim of architectural beauty for level bridges, it is well to state that it may be purchased at too great a cost, particularly in localities where the relative level of the roadway and of the adjacent ground would demand high embankments for the approaches.

561. *Style of Architecture.* The design and construction of a bridge should be governed by the same general principles as any other architectural composition. As the object of a bridge is to bear heavy loads, and to withstand the effects of one of the most destructive agents with which the engineer has to contend, the general character of its architecture should be that of strength. It should not only be secure, but to the apprehension appear so. It should be equally removed from Egyptian massiveness and Corinthian lightness; while, at the same time, it should conform to the features of the surrounding locality, being more ornate and carefully wrought in its minor details in a city, and near buildings of a sumptuous style, than in more obscure quarters; and assuming every shade of conformity, from that which would be in keeping with the humblest hamlet and tamest landscape to the boldest features presented by Nature and Art. Simplicity and strength are its natural characteristics; all ornament of detail being rejected which is not of obvious utility, and suitable to the point of view from which it must be seen; as well as all attempts at boldness of general design which might give rise to a feeling of insecurity, however unfounded in reality. The most, therefore, that can be tried in the way of mere ornament, even under the most favorable circumstances, will be to combine the voussoirs of the arches with the horizontal courses of the spandrels in a regular and suitable manner,—to add a projecting cornice, with supporting members if necessary, of an agreeable profile,—and to give such a form to the ends of the piers, termed the *starlings*, or *cut-waters*, as shall heighten the general pleasing effect. The heads of the bridge, the cornice, and the parapet should also generally present an unbroken outline; this, however, may be departed from in bridges where it is desirable to place recesses for seats, so as not to interfere with the footpaths; in which case a plain buttress may be built above each starling to support the recess and its seats, the utility of which will be obvious, while it will give an appearance of additional strength when the height of the parapet above the starlings is at all considerable.

562. *Construction.* The methods of laying the foundations of structures of stone, &c., described under the article of Ma-

sonry, being alike applicable to all structures which come under this denomination, there only remains to be added under this head whatever is peculiar to bridge-building. Either of the methods referred to may be employed in laying the foundations of the abutments and piers of a bridge, which, in the judgment of the engineer, may be most suited to the locality, and will be least expensive. As the foundations and their beds of the parts in question are greatly exposed, from the action of the current both upon the soil around them and upon the materials used for their construction, the utmost precaution should be taken to secure them from damage, by giving to the foundation-bed an ample spread where the soil is at all yielding; by selecting the most durable materials for the masonry of these parts; and by employing some suitable means for securing the bed of the natural water-way around and between the piers from being removed by the current.

563. Various expedients have been tried to effect this last object; among the most simple and efficacious of which is that of covering the surface to be protected by a bed of stone broken into fragments of sufficient bulk to resist the velocity of the current in the bays, if the soil is of an ordinary clayey mud; but, if it be of loose sand or gravel, the surface should be first covered by a bed of tenacious clay before the stone be thrown in. The voids between the blocks of stone, in time, become filled with a deposite of mud, which, acting as a cement, gives to the mass a character of great durability.

564. The foundation courses of the piers should be formed of heavy blocks of cut stone bonded in the most careful manner, and carried up in offsets. The faces of the piers should be of cut stone well bonded. They may be built either vertically, or with a slight batter. Their thickness at the impost should be greater than what would be deemed sufficient under ordinary circumstances; as they are exposed to the destructive action of the current, and of shocks from heavy floating bodies; and from the loss of weight of the parts immersed, owing to the buoyant effort of the water, their resistance is decreased. The most successful bridge architects have adopted the practice of making the thickness of the piers at the impost between one sixth and one eighth of the span of the arch. The thickness of the piers of the bridge of Neuilly, near Paris, built by the celebrated Perronet, whose works form an epoch in modern bridge architecture, is only one ninth of the span, its arches also being remarkable for the boldness of their curve.

565. The usual practice is to give to all the piers the same proportional thickness. It has however been recommended by some engineers to give sufficient thickness to a few of the piers

to resist the horizontal thrust of the arches on either side of them, and thus secure a part of the structure from ruin, should an accident happen to any of the other piers. These masses, to which the name *abutment piers* has been applied, would be objectionable from the diminution of the natural water-way that would be caused by their bulk, and from the additional cost for their construction, besides impairing the architectural effect of the structure. They present the advantage, in addition to their main object, of permitting the bridge to be constructed by sections, and thus procure an economy in the cost of the wooden centres for the arches.

566. The projection of the starlings beyond the heads of the bridge, their form, and the height given to them above the spring-ing lines, will depend upon local circumstances. As the main objects of the starlings are to form a *fender*, or *guard* to secure the masonry of the spandrels, &c., from being damaged by float-ing bodies, and to serve as a cut-water to turn the current aside, and prevent the formation of whirls, and their action on the bed around the foundations, the form given to them should subserve both these purposes. Of the different forms of horizontal section which have been given to starlings, (Figs. 107, 108, 109, 110,)

Fig. 107.

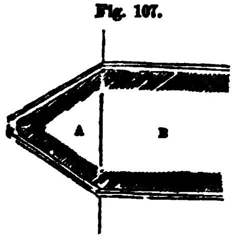


Fig. 108.

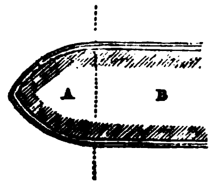


Fig. 109.

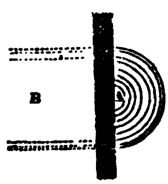
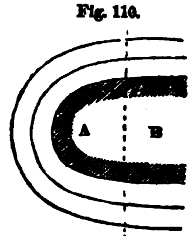


Fig. 110.



Figs. 107, 108, and 110—Represent horizontal sections of starlings A of the more usual forms, and part of the pier B above the foundation courses. Fig. 109 represents the plan of the hood of a starling laid in courses, the general shape being that of the quarter of a sphere.

the semi-ellipse, from experiments carefully made, with these ends in view, appears best to satisfy both objects.

The up and down stream starlings, in tidal rivers not subject to freshets and ice, usually receive the same projections, which, when their plan is a semi-ellipse, must be somewhat greater than the semi-width of the pier. Their general vertical outline is

columnar, being either straight or swelled, (Figs. 111, 112, 113, 114.) They should be built as high as the ordinary highest

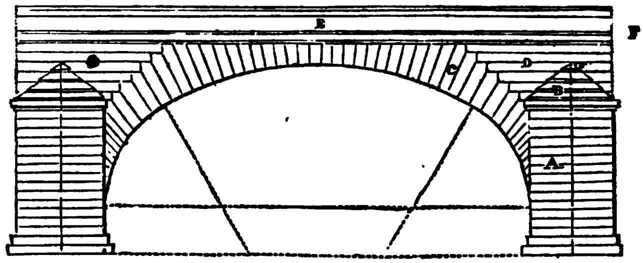


Fig. 111—Represents in elevation starlings A, their hoods B, the voussoirs C, the spandrels D and the combination of their courses and joints with each other in an oval arch of three centres.
E, parapet; F, cornice.

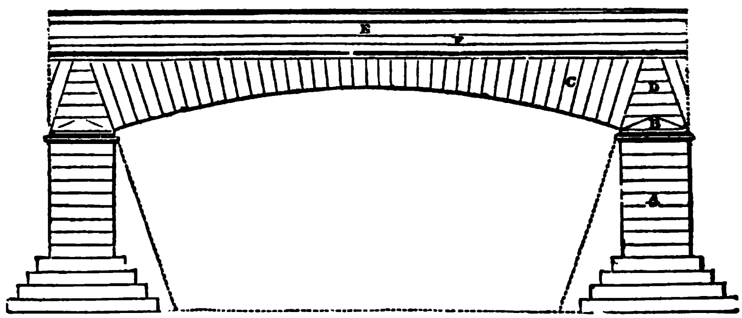


Fig. 112—Represents in elevation the combinations of the same elements as in Fig. 111 for a flat segmental arch.

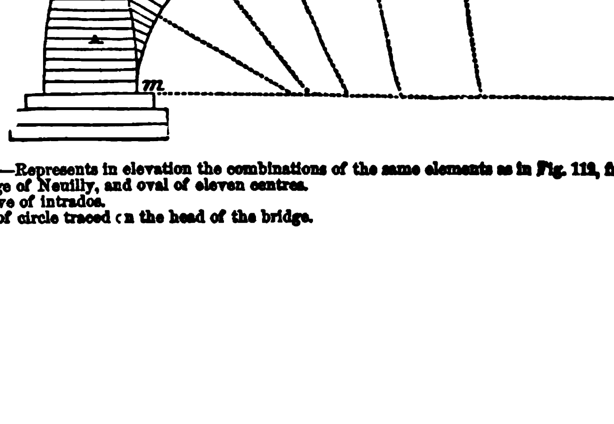


Fig. 113—Represents in elevation the combinations of the same elements as in Fig. 112, from the bridge of Neuilly, and oval of eleven centres.
om, curve of intrados.
on, arc of circle traced on the head of the bridge.

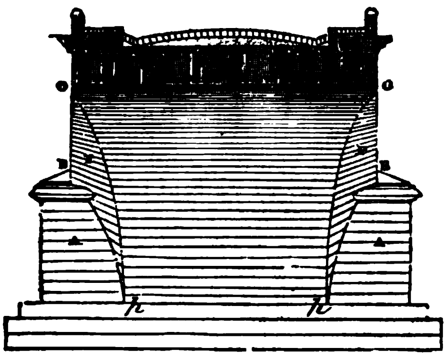


Fig. 114—Represents a cross section and elevation through the crown of Fig. 113, showing the arrangement also of the roadway, footpaths, parapet, and cornice.

water-level. They are finished at top with a coping stone to preserve the masonry from the action of rain, &c.: this stone, termed the *hood*, may receive a conical, a spheroidal, or any other shape which will subserve the object in view, and produce a pleasing architectural effect, in keeping with the locality.

In streams subject to freshets and ice, the up stream starlings should receive a greater projection than those down stream, and, moreover, be built in the form of an inclined plane (Fig. 115)

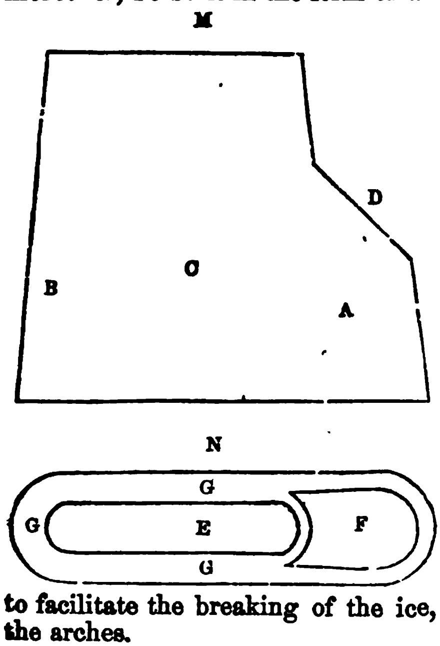


Fig. 115—Represents a side elevation M and plan N of a pier of the Potomac aqueduct, arranged with an ice-breaker starling.
A, up-stream starling, with the inclined ice-breaker D which rises from the low-water level above that of the highest freshets.
B, down-stream starling.
C, face of pier.
E, top of pier.
F, horizontal projection of top of ice-breaker.
GG, horizontal projection of faces of pier and starlings.

to facilitate the breaking of the ice, and its passage through the arches.

567. Where the banks of a water-course spanned by a bridge

are so steep and difficult of access that the roadway must be raised to the same level with their crests, security for the foundation, and economy in the construction demand that *hollow* or *open piers* be used instead of a solid mass of masonry. A construction of this kind requires great precaution. The facing courses of the piers must be of heavy blocks dressed with extreme accuracy. The starlings must be built solid. The faces must be connected by one or more cross tie-walls of heavy, well-bonded blocks; the tie-walls being connected from distance to distance vertically by strong tie-blocks; or, if the width of the pier be considerable, by a tie-wall along its centre line.

568. The foundations, the dimensions, and the form of the abutments of a bridge will be regulated upon the same principles as the like parts of other arched structures; a judicious conformity to the character of strength demanded by the structure, and to the requirements of the locality being observed. The walls which at the extremities of the bridge form the continuation of the heads, and sustain the embankments of the approaches,—and which, from their widening out from the general line of the heads, so as to form a gradual contraction of the avenue by which the bridge is approached, are termed the *wing-walls*,—serve as firm buttresses to the abutments. In some cases the back of the abutment is terminated by a cylindrical arch, (Fig. 116,) placed on end, or having its right-line elements ver-

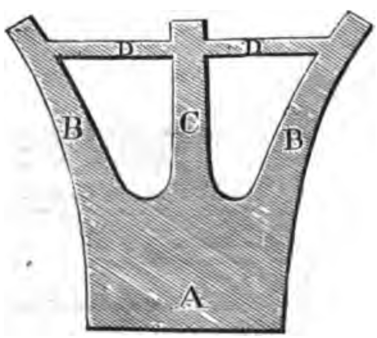


Fig. 116—Represents a horizontal section of an abutment A with curved wing-walls B, B, connected with a central buttress C and a cross tie-wall D.

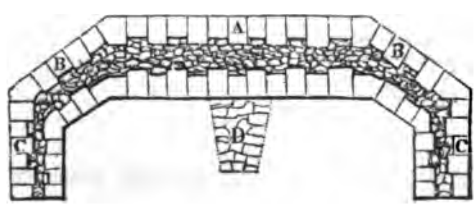


Fig. 117—Represents a horizontal section of an abutment A with straight wing-walls B, B, terminated by return-walls C, C. D, central buttress.

tical, which connects the two wing-walls. In others (Fig. 117)

a rectangular-shaped buttress is built back from the centre line of the abutment, and is connected with the wing-walls either by horizontal arches, or by a vertical cross tie-wall.

569. The wing-walls may be either plane surface walls (Fig. 118) arranged to make a given angle with the heads of the bridge,

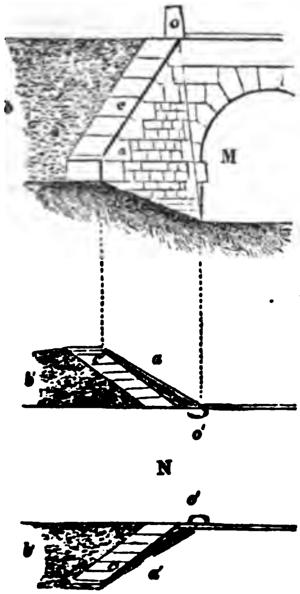


Fig 118—Represents an elevation M and plan N of a portion of a single arch bridge with straight wing-walls sustaining an embankment across the valley of the water-course.
a, a', face of wing-wall.
b, b', side slope of embankment.
c, c', top of wing-wall.
o, o', fender or guard stones.

or they may be curved surface-walls presenting their concavity, (Fig. 126,) or their convexity to the exterior; or of any other shape, whether presenting a continuous, or a broken surface, that the locality may demand. Their dimensions and form of profile will be regulated like those of any other sustaining wall; and they receive a suitable finish at top to connect them with the bridge, and make them conform to the outline of the embankments, or other approaches.

570. The arches of bridges demand great care in proportioning the dimensions of the voussoirs, and procuring accuracy in their forms, as the strength of the structure, and the permanence of its figure, will chiefly depend upon the attention bestowed on these points. Peculiar care should be given in arranging the masonry above the piers which lies between the two adjacent arches. In some of the more recent bridges, (Fig. 120,) this part is built up solid but a short distance above the imposts, generally not higher than a fourth of the rise, and is finished with a reversed

arch to give greater security against the effects of the pressure thrown upon it.

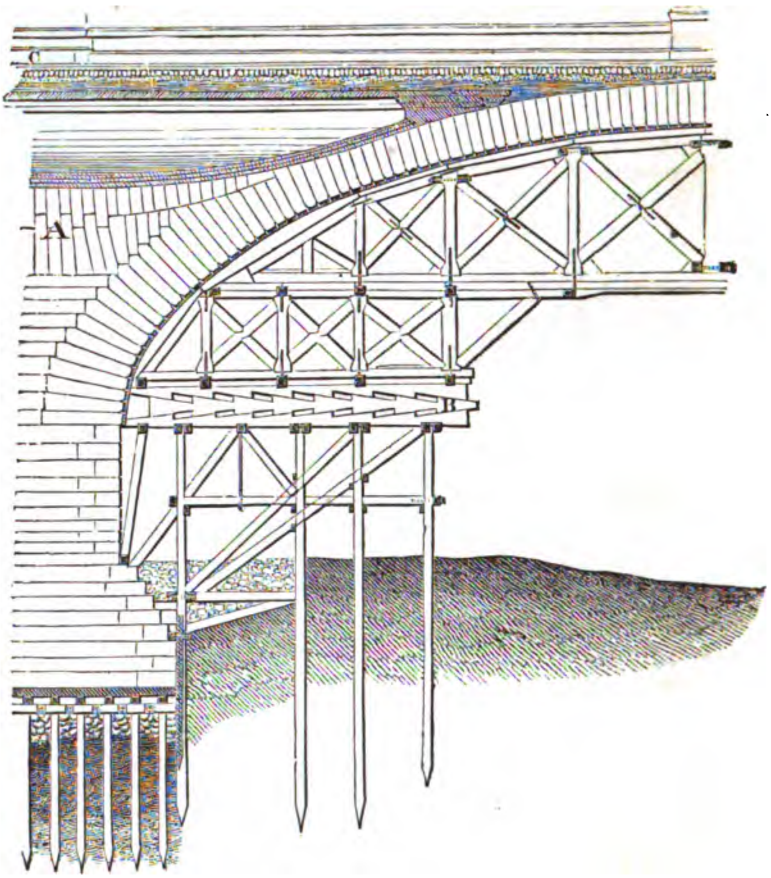


Fig. 120—Represents a longitudinal section of a portion of a pier and foundations, and of an arch and its centre of the new London bridge over the Thames.
A, finish of solid spandrel with reversed arch.
B, wedge of striking plates.
C, recess over the starlings for seats

The backs of the arches should be covered with a water-tight capping of beton, and a coating of asphaltum.

571. The entire spandrel courses of the heads are usually not laid until the arches have been uncentred, and have settled, in order that the joints of these courses may not be subject to any other cause of displacement than what may arise from the effects of variations of temperature upon the arches. The thickness of

the head-walls will depend upon the method adopted for supporting the roadway. If this be by a filling of earth between the head-walls, then their thickness must be calculated not only to resist the pressure of the earth which they sustain, but allowance must also be made for the effects of the shocks of floating bodies in weakening the bond, and separating the blocks from their mortar-bed. The more approved methods of supporting the roadway, and which are now generally practised, except for very flat segment arches, are to lay the road materials either upon broad flagging stones (Fig. 120, 121,) which rest upon thin brick walls built

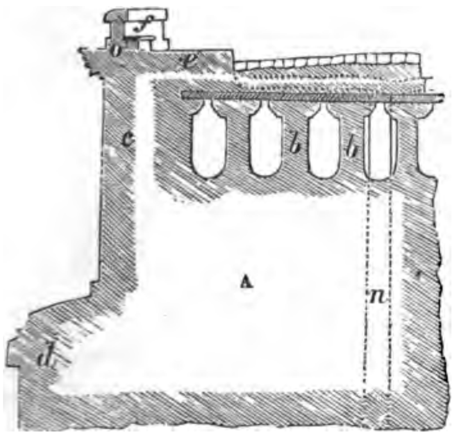


Fig. 121—Represents a profile of Fig. 120 through the centre of the pier, showing the arrangement of the roadway and its drainage, &c.
A, section of masonry of pier and spandrel.
b, b, sections of walls parallel to head-wall, which support the flagging stone on which the roadway is laid.
c, section of head-wall and buttress above the starling *d*.
e, footpath.
f, recess for seats over the buttress.
o, cornice and parapet.
n, vertical conduit in the pier communicating with two others under the roadway from the side channels.

parallel to the head-walls, and supported by the piers and arches; or by small arches, (Fig. 122,) for which these walls serve as piers; or by a system of small groined arches supported by pillars resting upon the piers and main arches. When either of these methods is used, the head-walls may receive a mean thickness of one fifth of their height above the solid spandrel.

572. *Superstructure.* The superstructure of a bridge consists of a cornice, the roadway and footpaths, &c., and a parapet.

The object of the cornice is to shelter the face of the head-walls from rain. To subserve this purpose, its projection beyond the surface to be sheltered should be the greater as the altitude of the sheltered part is the more considerable. This rule will require a cornice with supporting blocks, (Fig. 123,) termed *modillions*, below it, whenever the projecting part would be actually, or might seem insecure from its weight. The height of the cornice, including its supports, should generally be equal to its projections; this will often require more or less of detail in the profile of the cornice, in order that it may not appear heavy. The top surface of the cornice should be a little above

that of the footpath, or roadway, and be slightly sloped outward; the bottom should be arranged with a situable *larmier*,

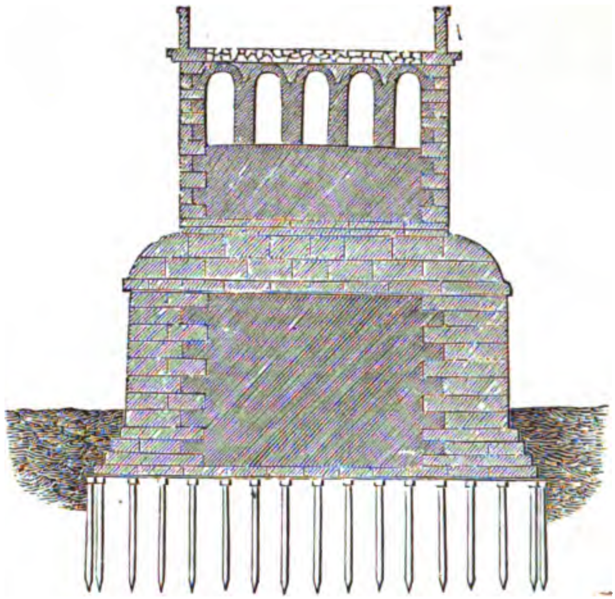


Fig. 122—Represents a section through the axis of a pier of bridge built of stone with brick filling, showing the arrangement for supporting the roadway on small arches.

or *drip*, to prevent the water from finding a passage along its under surface to the face of the wall.

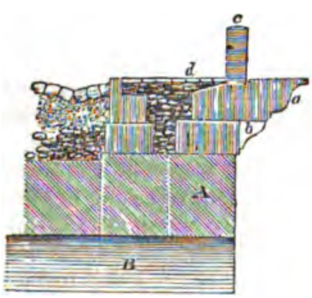


Fig. 123—Represents a section through the crown of an arch, showing the cornice *a*, modillion *b*, parapet *c*, and footpath *d*.
A, key-stones.
B, side elevation of soffit.

573. The parapet surmounts the cornice, and should be high enough to secure vehicles and foot-passengers from accidents, without however intercepting the view from the bridge. The parapet is usually a plain low wall of cut stone, surmounted by a coping slightly rounded on its top surface. In bridges which

have a character of lightness, like those with flat segment arches, the parapet may consist of alternate panels of plain wall and balustrades, provided this arrangement be otherwise in keeping with the locality. The exterior face of the parapet should not project beyond that of the heads. The blocks of which it is formed, and particularly those of the coping, should be firmly secured with copper or iron cramps.

574. The width of the roadway and of the footpaths will be regulated by the locality; being greatest where the thoroughfares connected by the bridge are most frequented. They are made either of broken, or of paving stone. They should be so arranged that the surface-water from rain shall run quickly into the side channels left to receive it, and be conducted from thence by pipes which lead to vertical conduits (Fig. 121) in the piers that have their outlets in one of the faces of the piers, and below the lowest water-level.

575. Strong and durable stone, dressed with the chisel, or hammer, should alone be used for the masonry of bridges where the span of the arch exceeds fifty feet. The interior of the piers, and the backing of the abutments and head-walls may, for economy, be of good rubble, provided great attention be bestowed upon the bond and workmanship. For medium and small spans a mixed masonry of dressed stone and rubble, or brick, may be used; and, in some cases, brick alone. In all these cases (Figs. 122, 124) the starlings,—the foundation courses,—the impost stone,—the ring courses, at least of the heads,—and the key-stone, should be of good dressed stone. The remainder may be of coursed rubble, or of the best brick, for the facing, with good rubble or brick for the fillings and backings. In a mixed masonry of this character the courses of dressed stone may project slightly beyond the surfaces of the rest of the structure. The architectural effect of this arrangement is in some degree pleasing, particularly when the joints are chamfered; and the method is obviously useful in structures of this kind, as protection is afforded by it to the surfaces which, from the nature of the material, or the character of the work, offer the least resistance to the destructive action of floating bodies. Hydraulic mortar should alone be used in every part of the masonry of bridges.

576. *Approaches.* The arrangement of the approaches will depend upon the number and direction of the avenues leading to the bridge,—the width of the avenues, and their position above or below the natural surface of the ground,—and the locality. The principal points to be kept in view in their arrangement are to procure an easy and safe access to the bridge for vehicles, and not to obstruct unnecessarily the channels, for purposes of navigation, which may be requisite under the extreme arches.

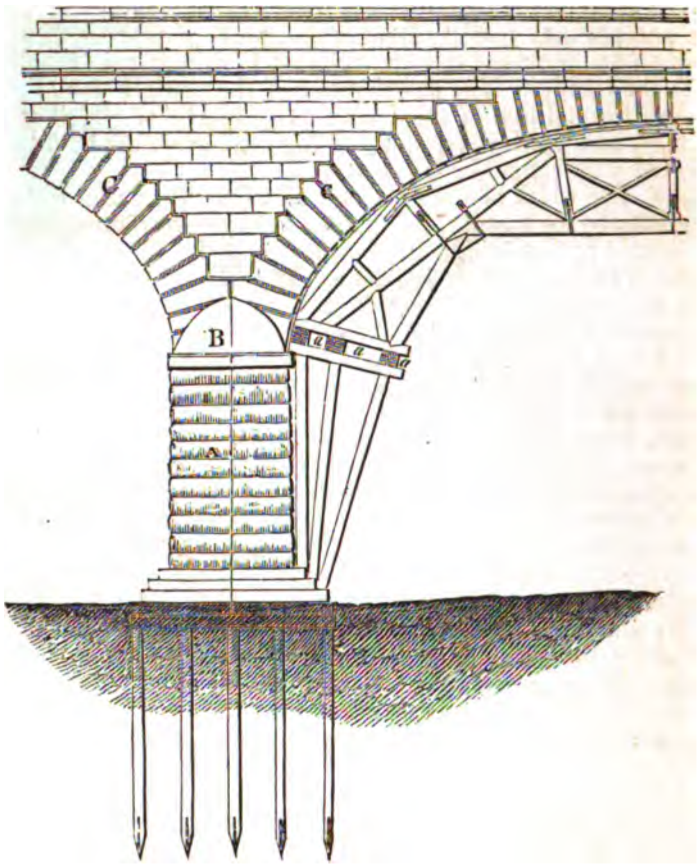


Fig. 124—Represents an elevation of a pier, a portion of two arches, and the centre of the bridge of which Fig. 122 is the section.
A, face of starling.
B, hood.
C, voussoirs with chamfered joints.

When the avenue to the bridge is, by an embankment, in the same line as its axis, and the roadway and bridge are of the same width, the head-walls of the bridge (Fig. 125) may be prolonged sufficiently far to allow the foot of the embankment slope to fall within a few feet of the crest of the slope of the water-course; this portion of the embankment slope being shaped into the form of a quarter of a cone, and reveted with dry stone or sods, to preserve its surface from the action of rain.

When several avenues meet at a bridge, or where the width of the roadway of a direct avenue is greater than that of the

bridge, the approaches are made by gradually widening the out-let from the bridge, until it attains the requisite width, by means of

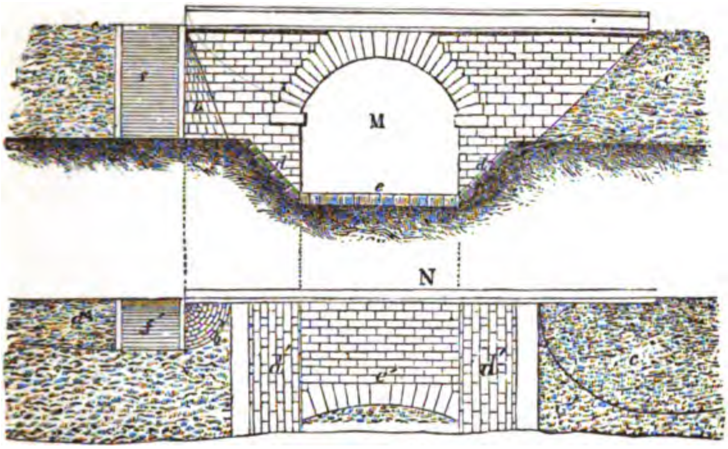


Fig. 125—Elevation M and plan N, showing the manner of arranging the embankments of the approaches, when the head-walls of the bridge are simply prolonged.
a, a′, side slope of embankment.
b, b′, dry stone facing of the embankment where its end is rounded off, forming a quarter of a cone finish.
f, f′, flight of steps for foot-passengers to ascend the embankment.
c, c′, embankment arranged as above, but simply sodded.
d, d′, facing of dry stone for the side slopes of the banks.
e, e′, facing of the bottom of the stream.

wing-walls of any of the usual forms that may suit the locality. The form of wing-wall (Fig. 126) presenting a concave surface outward is usually preferred when suited to the locality, both

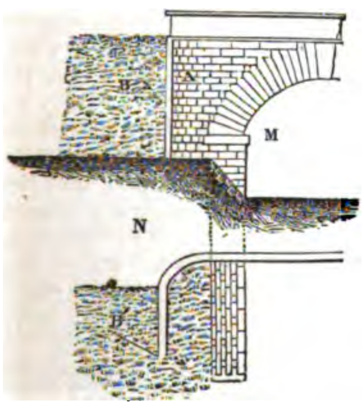


Fig. 126—Represent an elevation M and plan N of a curved face wing-wall.
A, front view of wing-wall.
B, B′, slope of embankment.

for its architectural effect and its strength. When made of dressed stone it is of more difficult construction and more expensive than the plane surface wall.

In order that the approaches may not obstruct the communications along the banks for the purposes of navigation, an arched passage-way will, in most cases, be requisite under the roadway of the approach and behind the abutment of the extreme arch, for horses, and, if necessary, vehicles. When the form of the arch will admit of it, as in flat segment arches, a roadway, projecting beyond the face of the abutment, may be made under the arch for the same purpose.

577. *Water-wings.* To secure the natural banks near the bridge, and the foundations of the abutments from the action of the current, a facing of dry stone, or of masonry, should be laid upon the slope of the banks, which should be properly prepared to receive it, and the foot of the facing must be secured by a mass of loose stone blocks spread over the bed around it, in addition to which a line of square-jointed piles may be previously driven along the foot. When the face of the abutment projects beyond the natural banks, an embankment faced with stone should be formed connecting the face with points on the natural banks above and below the bridge. By this arrangement, termed the *water-wings*, the natural water-way will be gradually contracted to conform to that left by the bridge.

578. *Enlargement of Water-way.* In the full centre and oval arches, when the springing lines are placed low, the spandrels present a considerable surface and obstruction to the current during the higher stages of the water. This not only endangers the safety of the bridge, by the accumulation of drift-wood and ice which it occasions, but, during these epochs, gives a heavy appearance to the structure. To remedy these defects the solid angle, formed by the heads and the soffit of the arch, may be truncated, the base of the cuneiform-shaped mass taken away being near the springing lines of the arch, and its apex near the crown. The form of the detached mass may be variously arranged. In the bridge of Neuilly, which is one of the first where this expedient was resorted to, the surface, marked F, (Figs. 113, 114,) left by detaching the mass in question, is warped, and lies between two plane curves, the one an arc of a circle *n o*, traced on the head of the bridge, the other an oval *m o o p*, traced on the soffit of the arch. This affords a funnel-shaped water-way to each arch, and, during high water, gives a light appearance to the structure, as the voussoirs of the head ring-course have then the appearance of belonging to a flat segmental arch.

579. *Centres.* The framing of centres, and the arrangement for striking them, having been already fully explained under the article Framing, with illustrations taken from some of the most celebrated recent structures, nothing further need be here added than to point out the necessity of great care both in the combi-

cation of the frame, and in its mechanical execution, in order to prevent any change in the form of the arch while under construction. The English engineers have generally been more successful in this respect than the French. The latter, in several of their finest bridges, used a form of centre composed of several polygonal frames, with short sides, so inscribed within each other that the angles of the one corresponded to the middle of the sides of the other. The sides of each frame were united by joints, and the series of frames secured in their respective positions by radial pieces, in pairs, notched upon and bolted to the frames, which they clamped between them. A combination of this character can preserve its form only under an equable pressure distributed over the back of the exterior polygon. When applied to the ordinary circumstances attending the construction of an arch, it is found to undergo successive changes of shape, as the voussoirs are laid on it; rising first at the crown, then yielding at the same point when the key-stone and the adjacent voussoirs are laid on. The English engineers have generally selected those combinations in which, the pressures being transmitted directly to fixed points of support, no change of form can take place in the centre but what arises from the contraction or elongation of the parts of the frame.

580. *General Remarks.* The architecture of stone bridges has, within a somewhat recent period, been carried to a very high degree of perfection, both in design and in mechanical execution. France, in this respect, has given an example to the world, and has found worthy rivals in the rest of Europe, and particularly in Great Britain. Her territory is dotted over with innumerable fine monuments of this character, which attest her solicitude as well for the public welfare as for the advancement of the industrial and liberal arts. For her progress in this branch of architecture, France is mainly indebted to her School and her Corps of *Ponts et Chaussées;* institutions which, from the time of her celebrated engineer Perronet, have supplied her with a long line of names, alike eminent in the sciences and arts which pertain to the profession of the engineer.

England, although on some points of mechanical skill pertaining to the engineer's art the superior of France, holds the second rank to her in the science of her engineers. Without establishments for professional training corresponding to those of France, the English engineers, as a body, have, until within a few years, labored under the disadvantage of having none of those institutions which, by creating a common bond of union, serve not only to diffuse science throughout the whole body, but to raise merit to its proper level, and frown down alike, through an enlightened *esprit de corps*, the assumptions of ignorant pretension, and the

malevolence of petty jealousies. Although, as a body, less advantageously placed, in these respects, than their more thorough-bred brethren of France, the engineers of England can point, with a just feeling of pride, not only to the monuments of their skill, but to individual names among them which, achieved under the peculiar obstacles ever attendant upon self-education, yet stand in the first rank of those by whose genius the industrial arts have been advanced and ennobled.

The other European States have also contributed largely to bridge architecture, although their efforts in this line are less widely known through their publications than those of France and England. Among the many bridges belonging to Italy, may be justly cited the far-famed *Rialto*; the bridge of *Santa Trinita* at Florence, the curve of whose intrados was so long a mathematical puzzle; and the recent single arch over the *Dara Riparia* near Turin.

In the United States, the pressing immediate wants of a young people, who are still without that accumulated capital by which alone great and lasting public monuments can be raised, have prevented much being done, in bridge building, except of a temporary character. The bridges, viaducts, and aqueducts of stone in our country, almost without an exception, have been built of rustic work through economical considerations. The selection of this kind of masonry, independently of its cheapness, has the merit of appropriateness, when taken in connection with the natural features of the localities where most of these structures are placed. Among the works of this class, may be cited the railroad bridge, called the *Thomas Viaduct*, over the Patapsco, on the line of the Baltimore and Washington railroad, designed and built by Mr. B. H. Latrobe, the engineer of the road. This is one of the few existing bridge structures with a curved axis. The engineer has very happily met the double difficulty before him, of being obliged to adopt a curved axis, and of the want of workmen sufficiently conversant with the application of working drawings of a rather complicated character, by placing full centre cylindrical arches upon piers with a trapezoidal horizontal section. This structure, with the exception of some minor details in rather questionable taste, as the slight iron parapet railing, for example, presents an imposing aspect, and does great credit to the intelligence and skill of the engineer, at the time of its construction, but recently launched in a new career. The fine single arch, known as the *Carrolton Viaduct*, on the Baltimore and Ohio railroad, is also highly creditable to the science and skill of the engineer and mechanics under whom it was raisd. One of the largest bridges in the United States, designed and partly executed in stone, is the *Potomac Aqueduct* at Georgetown, where the Chesapeake and Ohio canal

intersects the Potomac river. This work, to which a wooden superstructure has been made, was built under the superintendence of Captain Turnbull of the U. S. Topographical Engineers. In the published narrative of the progress of this work, a very full account is given of all the operations, in which, while the resources and skill of the engineer, in a very difficult and, to him, untried application of his art, are left to be gathered by the reader from the successful termination of the undertaking, his failures are stated with a candor alike creditable to the man, and worthy of imitation by every engineer who prizes the advancement of his art above that personal reputation which a less truthful course may place in prospect before him.

581. The following table contains a summary of the principal details of some of the more noted stone bridges of Europe.

NAME OF BRIDGE.	River.	Form of Arch.	Numb. of arches.	Span of widest span.	Rise.	Depth of key-stone.	Width between the heads.	Date.	Name of engineer.
Vieille-Brioude .	Allier.	Segment.	1	178	69	5.3	–	1454	Grenier & Estone.
Rialto	—	"	1	98.6	23	–	–	1578	Michel Angelo.
Claix	Drac.	"	1	150	54	3.1	–	1611	—
Neuilly (A) . .	Seine.	Elliptical.	5	127.9	31.9	5.3	47.9	1774	Perronet.
Lavaur	Agout.	"	1	160.5	65	10.9	–	1775	Saget.
Saint-Maxence (B)	Oise.	Segment.	3	76.7	6	5	41.5	1784	Perronet.
Gignac	Erault.	Elliptical.	1	160	44	6.5	–	1793	Garipuy.
Jena (C) . . .	Seine.	Segment.	5	91.8	10.8	4.6	43.7	1811	Lamandé.
Rouen	Seine.	"	5	101.7	13.7	4.6	49.2	1813	Lamandé.
Waterloo (D) . .	Thames.	Elliptical.	9	120	35	4.9	45	1816	Rennie.
Gloucester (E) .	Severn.	"	1	150	54	4.5	35	1827	Telford.
London (F) . .	Thames.	"	5	152	37.8	5	56	1831	Rennie.
Turin (G) . . .	Dora Riparia	Segment.	1	147.6	18	4.9	40	–	Mosca.
Grosvenor (H) .	Dee.	"	1	200	42	4		1833	Hartley.

(A) This fine structure, designed and built by the celebrated Perronet, forms an epoch in bridge architecture, from the boldness of its design, its skilful mechanical execution, and the simple but appropriate character of its architectural details. The curve of the intrados is an oval of eleven centres, the radius of the arc at the spring being 20.9 feet, and that of the arc at the crown 159.1 feet. The engineer conceived the idea of giving to the soffit a funnel shape, by widening it at the heads, from the crown to the springing line. This he effected by connecting the soffit of each arch and the heads by a warped surface, which passed, on the one hand, through a flat circular arc, described upon the heads through the points of the crown and the top of the two adjacent starlings, and, on the other, through two curves on the soffit, cut out by two vertical planes, oblique to the axis, passed through the highest point of the curve on the heads, and through points on the two respective springing lines of the arch. The object of this arrangement was twofold; first,—as the springing lines were placed at the low-water level, the bridge, during the seasons

of high water, would have appeared rather heavy, as the greater part of the soffit, at this period, would have been under water,—it gave the bridge a lighter appearance during the epochs of high water; and, second, as the obstruction to the free flow of the water from the spandrels would be very considerable at the same periods, the funnel form given to the soffit at the heads partially remedied this inconvenience.

The axis of the roadway, the cornice, and all the corresponding architectural lines were made horizontal, a feature in bridge architecture which the reputation of Perronet has since rendered classical; and to obtain which points truly essential conditions have in some more recent structures been sacrificed.

The abutments are 32 feet thick at the springing lines, and the piers but 13.8 feet at the same point, giving an example of judicious boldness combined with adequate strength, on scientific principles, which had been partially lost sight of by preceding engineers in designing this part of bridges.

The centres of the Neuilly bridge were designed upon the faulty principle of concentric polygonal frames. Perronet was aware of the inconveniences of this combination, and in no part of the construction of the bridge than in this was more sagacious forethought displayed by him, in providing for foreseen contingencies, nor greater resources and skill in remedying those which could not have been anticipated. An oversight, rather more serious in its consequences, was committed in widening the natural water-way of the river where the bridge was erected; the effect of this has been a gradual deposition near the bridge, and an obstruction of the navigable channels.

The bridge of Neuilly is a noble monument of the genius and practical skill of its engineer. The style of its architecture, both as a whole and in its several parts, is imposing and in the best taste.

(B) This bridge was built after the designs of Perronet. Seduced by a thorough knowledge of the capabilities of his art, the engineer was led, in planning this structure, into the error of sacrificing apparent strength, for the purpose of producing great boldness and lightness of design. This he effected by placing very flat segment arches upon piers formed of four columns; the two, forming the starlings, being united to the two adjacent by a connecting wall, an interval being left between the two centre columns. The diameters of the columns are 9.6 feet, with the same interval between them.

The engineer who constructed the bridge, apprehensive apparently for its safety, introduced into the courses of the piers and of the arches a large quantity of iron ties and cramping pieces, a measure of precaution which, if necessary, ought to have con

demned the original designs, although supported by the high authority of Perronet, and caused others to be substituted for them.

(C) This bridge, now designated as the *Pont de l'Ecole Militaire*, from its locality, and the bridge of *Rouen*, are built upon nearly the same designs. The former is a model of architectural taste and of skilful workmanship. Its horizontal architectural lines, its fine cornice, copied from that of the temple of *Mars* the *Avenger*, and the sculptured wreath on its spandrels, form a whole of singular beauty.

(D) This bridge, designated when first built as the *Strand Bridge*, is worthy of the great metropolis in which it is placed. The engineer, influenced perhaps by other examples of the same character in the vicinity of this structure, has placed small columns upon the starlings, which support recesses with seats for foot-passengers, and has thus, in no inconsiderable degree, deprived the bridge of that imposing character which its massiveness, and the excellent material of which it is built, could not otherwise have failed to produce.

(E) This fine elliptical arch is, in some respects, built in imitation of the Neuilly bridge, with a funnel-shaped soffit. Its general architectural effect is heavy, and its mere ornamental parts are in questionable taste. The details of its construction are alike monuments of the eminent professional skill, and of the truthfulness of character of the great engineer who planned and superintended it. In his narrative of the work, Mr. Telford takes blame to himself for oversights and unanticipated results, in which the scrupulous care that he conscientiously brought to every undertaking committed to him is unwittingly thrown into bolder relief, by the very confession of his failures; and a lesson of instruction is conveyed, more pregnant with important consequences to the advancement of his profession than the recording of hundreds of successful instances only could have furnished.

(F) This noble work of Sir John Rennie must ever rank among the master-pieces of bridge architecture, in every point by which this class of structures should be distinguished. For boldness, strength, simplicity, massiveness without heaviness, and a happy adaptation of design to the locality, it stands unrivalled. The beauty which is generally recognised in a level bridge has, in this, been judiciously sacrificed to a well-judged economy; and the artificial approaches have thus been accommodated to the existing, by decreasing the dimensions of the arches from the centre to the two extremities. The square plain buttresses, which rise above the starlings and support the recesses for seats, are of farther obvious utility in strengthening the head-walls, which, at these points are of considerable height; and they also

produce, in this case, a not unpleasing architectural effect, in separating the unequal arches, without impairing the unity of the general design.

(G) This is the boldest single arch of stone now standing, and is a splendid example of architectural design and skilful workmanship. The soffit of the arch is made slightly funnel-shaped, which gives the bridge an air of almost too great boldness. The cornice, which is copied from the same model as that of the bridge of Jena; the convex cylindrical-shaped wing-walls, which give an approach of 144 feet between the parapets; with the other architectural accessories, have made this bridge a model of good taste for imitation under like circumstances. From the omission of a usual architectural member, there is perhaps a slight feeling of nakedness produced on the mind of the rigid *connoisseur* in art, on first seeing this structure, and its beauty is in some degree marred by this want.

The abutments of this bridge are 40 feet thick at the foundations, and, besides the wing-walls, are strengthened by two counterforts 20 feet long and 10 feet wide.

(H) The span of this arch is the widest on record. For architectural effect this bridge presents but little to the eye that is commendable; for this the engineer who superintended it is hardly responsible, except so far as, from professional sympathy and respect for a deceased member of the profession, he was led to adopt the designs of another. The abutments form a continuation of the arch; and the other details of the construction throughout exhibit that thorough acquaintance with their art for which the Hartleys, father and son, are well known to the profession.

582. The practice of bridge building is now generally the same throughout the civilized world. In France, the method of laying the foundations by caissons has, in most of their later works, been preferred by her engineers to that of coffer-dams; and in the superstructure of their bridges the French engineers have generally filled in, between the arches and the roadway, with solid material. In some of these bridges, as in that of *Bordeaux*, where apprehension was felt for the stability of the piling, a mixed masonry of stone and brick was used, and the roadway was supported by a system of light-groined arches of brick. Among the recent French bridges, presenting some interesting features in their construction, may be cited that of *Souillac* over the Dordogne. The river at this place having a torrent-like character, and the bed being of lime-stone rock with a very uneven surface, and occasional deep fissures filled with sand and gravel, the obstacle to using either the caisson, or the ordinary coffer-dam for the foundations, was very great. The engineer, M. Vicat, so well known by his researches upon mortar, &c., devised, to obviate these

difficulties, the plan of enclosing the area of each pier by a coffer-work accurately fitted to the surface of the bed, and of filling this with beton to form a bed for the foundation courses. This he effected, by first forming a frame-work of heavy timber, so arranged that thick sheeting-piles could be driven close to the bottom, between its horizontal pieces, and form a well-jointed vessel to contain the semi-fluid material for the bed. After this coffer-work was placed, the loose sand and gravel was scooped from the bottom, the asperities of the surface levelled, and the fissures were voided, and refilled with fragments of a soft stone, which it was found could be more compactly settled, by ramming, in the fissures, than a looser and rounder material like gravel. On this prepared surface, the bed of beton, which was from 12 to 15 feet in thickness, was gradually raised, by successive layers, to within a few feet of the low-water level, and the stone superstructure then laid upon it, by using an ordinary coffer-dam that rested on the frame-work around the bed. In this bridge, as in that of Bordeaux, a provisional trial-weight, greater than the permanent load, was laid upon the bed, before commencing the superstructure.

To give greater security to their foundations, the French usually surround them with a mass of loose stone blocks thrown in and allowed to find their own bed. Where piles are used and project some height above the bottom, they, in some cases, use, besides the loose stone, a grating of heavy timber, which lies between and encloses the piling, to give it greater stiffness and prevent outward spreading. In streams of a torrent character, where the bed is liable to be worn away, or shifted, an artificial covering, or apron of stone laid in mortar, has, in some cases, been used, both under the arches and above and below the bridge, as far as the bed seemed to require this protection. At the bridge of Bordeaux loose stone was spread over the river-bed between the piers, and it has been found to answer perfectly the object of the engineer, the blocks having, in a few years, become united into a firm mass by the clayey sediment of the river deposited in their interstices. At the elegant cast-iron bridge, built over the *Lary* near Plymouth, resort was had to a similar plan for securing the bed, which is of shifting sand. The engineer, Mr. Rendel, here laid, in the first place, a bed of compact clay upon the sand bed between the piers, and imbedded in it loose stone. This method, which for its economy is worthy of note, has fully answered the expectations of the engineer.

The English engineers have greatly improved the method of centring, and, in their boldest arches, any settling approaching that which the French engineers usually counted upon, on striking their centres, would now be regarded as an evidence of great de

fect in the design, or of very unskilful workmanship. They have generally, in their recent bridges, supported their roadway either upon flat stones, resting on light walls built parallel to the heads, or else upon light cylindrical arches laid upon piers having the same direction. In the preparation for laying the beds of their foundations, they have generally preferred the coffer-dam to any other plan, although in many localities the most expensive, on account of the greater facility and security offered by it for carrying on the work. They have not, until recently, made as extensive an application of beton as the French for hydraulic purposes, and, from having mostly used what is known as concrete among their architects, have met with some signal failures in its employment for these purposes.

WOODEN BRIDGES.

583. A wooden bridge consists of three essential parts: 1st, the abutments and piers which form the points of support for the bridge frame; 2d, the bridge frame which supports the superstructure between the piers and abutment; 3d, the superstructure, consisting of the roadway, parapets, roofing, &c.

584. The abutments and piers may be either of stone, or of timber. Stone supports are preferable to those of timber, both on account of the superior durability of stone, and of its offering more security than frames of timber against the accidents to which the piers of bridges are liable from freshets, ice, &c.

585. The forms, dimensions, and construction of stone abutments and piers for wooden bridges will depend, like those for stone bridges, upon local circumstances, and the kind of bridge-frame adopted. If the bridge-frame is so arranged that no lateral thrust is received from it by the piers, the dimensions of the latter should be regulated to support the weight of the bridge-frame and its superstructure, and to resist any action arising from accidental causes, as freshets, ice, &c. The forms and dimensions of the abutments, under the like circumstances, will be mainly regulated by the pressure upon them from the embankments of the approaches.

586. If the bridge-frame is of a form that exerts a lateral pressure, the dimensions of the abutments and piers must be suitably adapted to resist this action, and secure the supports from being overturned. Abutment-piers may be used with advantage in this case, as offering more security to the structure than simple piers, when a frame between any two supports may require to be taken out for repairs. The starlings should in all cases be carried above the line of the highest water-level, and the portion of the pier above this line, which supports the roadway bearers may be built with plane faces and ends.

587. Wooden abutments may be formed by constructing what is termed a *crib-work*, which consists of large pieces of square timber laid horizontally upon each other, to form the upright, or sloping faces of the abutment. These pieces are halved into each other at the angles, and are otherwise firmly connected together by diagonal ties and iron bolts. The space enclosed by the crib-work, which is usually built up in the manner just described, only on three sides, is filled with earth carefully rammed, or with dry stone, as circumstances may seem to require.

A wooden abutment of a more economical construction may be made, by partly imbedding large beams of timber placed in a vertical or an inclined position, at intervals of a few feet from each other, and forming a facing of thick plank to sustain the earth behind the abutment. Wooden piers may also be made according to either of the methods here laid down, and be filled with loose stone, to give them sufficient stability to resist the forces to which they may be exposed; but the method is clumsy, and inferior, under every point of view, to stone piers, or to the methods which are about to be explained.

588. The simplest arrangement of a wooden pier consists (Fig. 127) in driving heavy square or round piles in a single row, placing them from two to four feet apart. These upright

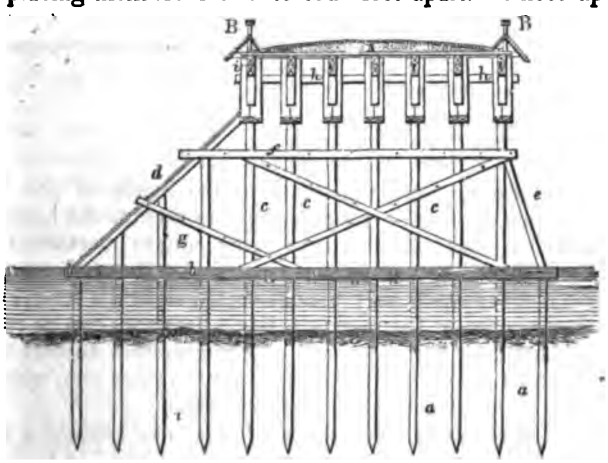


Fig. 127—Elevation of a wooden pier.
a, *a*, piles of substructure.
b, *b*, capping of piles arranged to receive the ends of the uprights *c*, *c*, which support the string pieces *i*, *i*.
d, upper fender beam.
e, lower fender beam.
f, horizontal ties bolted in pairs on the uprights.
g, *g*, diagonal braces bolted in pairs on the uprights.
h, capping of the uprights placed under the string pieces
A, roadway
B, parapet.

pieces are sawed off level, and connected at top by a horizontal beam, termed a *cap*, which is either mortised to receive a tenon made in each upright, or else is fastened to the uprights by bolts or pins. Other pieces, which are notched and bolted in pairs on the sides of the uprights, are placed in an inclined, or diagonal position, to brace the whole system firmly. The several uprights of the pier are placed in the direction of the thread of the current If thought necessary, two horizontal beams, arranged like the diagonal pieces, may be added to the system just below the lowest water-level. In a pier of this kind, the place of the starlings is supplied by two inclined beams on the same line with the uprights, which are termed *fender-beams*.

589. A strong objection to the system just described, arises from the difficulty of replacing the uprights when in a state of decay. To remedy this defect, it has been proposed to drive large piles in the positions to be occupied by the uprights, (Fig 128,) to connect these piles below the low-water level by four

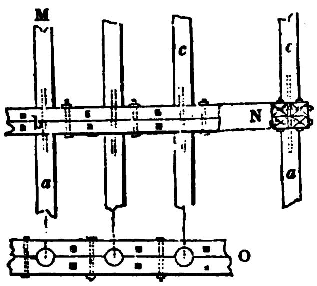


Fig. 128—Plan O, elevation M, and cross section N, showing the arrangement of the capping of the foundation piles with the uprights.
a, piles.
b, capping of four beams bolted together.
c, uprights.

horizontal beams, firmly fastened to the heads of the piles, which are sawed off at a proper height to receive the horizontal beams. The two top beams have large square mortises to receive the ends of the uprights, which rest on those of the piles. The rest of the system may be constructed as in the former case. By this arrangement the uprights, when decayed, can be readily replaced, and they rest on a solid substructure not subject to decay; shorter timber also can be used for the piers than when the uprights are driven into the bed of the stream.

590. In deep water, and especially in a rapid current, a single row of piles might prove insufficient to give stability to the uprights; and it has therefore been proposed to give a sufficient spread to the substructure to admit of bracing the uprights by struts on the two sides. To effect this, three piles (Fig. 129) should be driven for each upright; one just under its position, and the other two on each side of this, on a line perpendicular to that of the pier. The distance between the three piles will depend on the inclination and length that it may be deemed necessary to

give the struts. The heads of the three piles are sawed off level and connected by two horizontal clamping pieces below the low

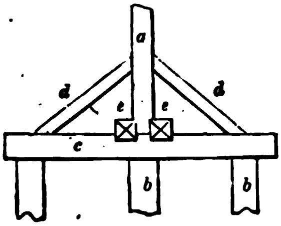


Fig. 129—Elevation of the arrangement of a wide foundation for a wooden pier.
a, upright.
b, b, piles of the foundation.
c, c, capping of the piles.
d, d, struts to strengthen the uprights.
e, e, clamping pieces bolted in pairs on the uprights.

est water. A square mortise is left in these two pieces, over the middle pile, to receive the uprights. The uprights are fastened together at the bottom by two clamping pieces, which rest on those that clamp the heads of the piles, and are rendered firmer by the two struts.

591. In localities where piles cannot be driven, the uprights of the piers may be secured to the bottom by means of a grating, arranged in a suitable manner to receive the ends of the uprights. The bed, on which the grating is to rest, having been suitably prepared, it is floated to its position, and sunk either before or after the uprights are fastened to it, as may be found most convenient. The grating is retained in its place by loose stone. As a farther security for the piers, the uprights may be covered by a sheathing of boards, and the spaces between the sheathing be filled in with gravel. Wooden piers may also be constructed, if necessary, of two parallel rows of uprights placed a few feet apart, and connected by cross and diagonal ties and braces.

592. As wooden piers are not of a suitable form to resist heavy shocks, ice-breakers should be placed in the stream, opposite to each pier, and at some distance from it. In streams with a gen-

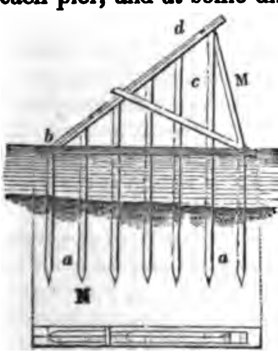


Fig. 130—Elevation M and plan N of a simple ice-breaker.
a, a, foundation piles.
b, b, capping of piles.
c, c, uprights.
d, inclined fender-beam shod with iron.

tle current, a simple inclined beam (Fig. 130) covered with thick sheet iron, and supported by uprights and diagonal pieces, will

be all that is necessary for an ice-breaker. But in rapid currents a crib-work, having the form of a triangular pyramid, (Fig. 131,

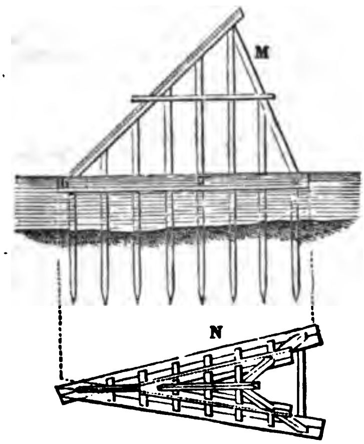


Fig. 131—Elevation M and plan N of the frame of an ice-breaker to be filled in with broken stone

the up-stream edge of which is covered with iron, will be required, to offer sufficient resistance to shocks. The crib-work may be filled in, if it be deemed advisable, with blocks of stone.

593. The width of the bays in wooden bridges will depend on the local circumstances. As a general rule, the bays may be wider, and in bridge-frames of curved timber the rise less, than in stone bridges. In arranging this point, the engineer must take into consideration the fact that wooden bridges require more frequent repairs than those of stone, arising from the decay of the material, and from the effects of shrinking and vibrations upon the joints of the frames, and that the difficulty of replacing decayed parts, and readjusting the frame-work, increases rapidly with the span.

594. Bridge-frames may be divided into two general classes. To the one belong all those combinations, whether of straight or of curved timber, that exert a lateral pressure upon the abutments and piers, and in which the superstructure is generally above the bridge-frame. To the other, those combinations which exert no lateral pressure upon the points of support, and in which the road way, &c. may be said to be suspended from the bridge-frame.

595. Any of the combinations, whether of straight, or of curved timber, described under the head of Framing, may be used for bridges, according to the width of bay selected. A preference, within late years, has been generally given by engineers to combinations of straight timber over curved frames, from the greater simplicity and facility of their construction, as well as their greater economy; as curved frames require much more iron in

the form of bolts, ties, &c., than frames of straight timber, and more costly mechanical contrivances for putting the parts together, and setting the frame upon its supports.

596. The number of ribs in the bridge-frame will depend on the general strength required by the object of the structure, and upon the class of frame adopted. In the first class, in which the roadway is usually above the frames, any requisite number of ribs may be used, and they may be placed at equal intervals apart, or else be so placed as to give the best support to the loads which pass over the bridge. In the second class, as the frame usually lies entirely, or projects partly above the roadway, &c., if more than two ribs are required, they are so arranged that one or two, as circumstances may demand, form each head of the bridge, and one or two more are placed midway between the heads, so as to leave a sufficient width of roadway between the centre and adjacent ribs. The footpaths are usually, in this case, either placed between the two centre ribs, or, when there are two exterior ribs, between them.

597. The manner of constructing the ribs, and of connecting them by cross ties and diagonal braces, is the same for bridge frames as for other wooden structures; care being taken to obtain the strength and stiffness which are peculiarly requisite in wooden bridges, to preserve them from the causes of destructibility to which they are liable. In frames which exert a lateral pressure against the abutments and piers, the lowest points of the frame-work should be so placed as to be above the ordinary high-water level; and plates of some metal should be inserted at those points, both of the frame and of the supports, where the effect of the pressure might cause injury to the woody fibre.

598. The roadway usually consists of a simple flooring formed of cross joists, termed the *roadway-bearers*, or *floor-girders*, and flooring-boards, upon which a road-covering either of wood, or stone is laid. A more common and better arrangement of the roadway, now in use, consists in laying longitudinal joists of smaller scantling upon the roadway-bearers, to support the flooring-boards. This method preserves more effectually than the other the roadway-bearers from moisture. Besides, in bridges which, from the position of the roadway, do not admit of vertical diagonal braces to stiffen the frame-work, the only means, in most cases, of effecting this object is in placing horizontal diagonal braces between each pair of roadway-bearers For like reasons, stone road-coverings for wooden bridges are generally rejected, and one of plank used, which, for a horse track, should be of two thicknesses, so that, in case of repairs, arising from the wear and tear of travel, the boards resting upon the flooring-joists may not require to be removed The footpaths

consist simply of a slight flooring of sufficient width, which is usually detached from and raised a few inches above the roadway surface.

599. When the bridge-frame is beneath the roadway, a distinct parapet will be requisite for the safety of passengers. This may be formed either of wood, of iron, or of the two combined. It is most generally made of timber, and consists of a hand and foot rail connected by upright posts and stiffened by diagonal braces A wooden parapet, besides the security it gives to passengers, may be made to add both to the strength and stiffness of the bridge, by constructing it of timber of a suitable size, and connecting it firmly with the exterior ribs.

600. In bridge frames in which the ribs are above the roadway, a timber sheathing of thin boards will be requisite on the sides, and a roof above, to protect the structure from the weather. The tie-beams of the roof-trusses may serve also as ties for the ribs at top, and may receive horizontal diagonal braces to stiffen the structure, like those of the roadway-bearers. The rafters, in the case in which there is no centre rib, and the bearing, or distance between the exterior ribs, is so great that the roadway-bearers require to be supported in the middle, may serve as points of support for suspension pieces of wood, or of iron, to which the middle point of the roadway-bearers may be attached.

601. When the bridge-frame is beneath the roadway, the flooring, if sufficient projection be given it beyond the head, will protect it from the weather, if the depth of the ribs be not very great. In the contrary case a side sheathing of boards may be requisite.

602. The frame and other main timbers of a wooden bridge will not require to be coated with paint, or any like composition, to preserve them from decay when they are roofed and boarded in to keep them dry. When this is not the case, the ordinary preservatives against atmospheric action may be used for them. The under surface and joints of the planks of the roadway may be coated with bituminous mastic when used for a horse-track; in railroad bridges a metallic covering may be suitably used when the bridge is not traversed by horses.

603. Wooden bridges can produce but little other architectural effect than that which naturally springs up in the mind of an educated spectator in regarding any judiciously-contrived structure. When the roadway and parapet are above the bridge-frame, a very simple cornice may be formed by a proper combination of the roadway-timbers and flooring, which, with the parapet, will present not only a pleasing appearance to the eye, but will be of obvious utility in covering the parts beneath from the weather. In covered bridges, the most that can be done will be to paint them with a uniform coat of some subdued tint. A

best, from their want of height as compared with their length, covered wooden bridges must, for the most part, be only unsightly and also apparently insecure structures when looked at from such a point of view as to embrace all the parts in the field of vision; and any attempt, therefore, to disguise their true character, and to give them by painting the appearance of houses, or of stone arches, while it must fail to deceive even the most ignorant, will only betray the bad taste of the architect to the more enlightened judge.

604. The art of erecting wooden bridges has been carried to great perfection in almost every part of the world where timber has, at any period, been the principal building material at the disposal of the architect. The more modern wooden bridges of Switzerland and Germany occupy in Europe the first rank, for boldness of design and scientific combination in their arrangement and construction. These fine foreign structures have been even surpassed in the United States, and our wooden bridges and the skill of our engineers and carpenters, as shown through them, have become deservedly celebrated throughout the scientific world. The more recent structures of this class are peculiarly characterized for simplicity of arrangement, perfection in the mechanical execution, and boldness of design. If they are open to the charge of any fault, it is to that of too great boldness of design, in spanning very wide bays with ribs of open-built beams either unsupported, or but imperfectly so, at intermediate points, by any combination of struts and corbels, or straining beams. The want of these additions is more or less apparent in the great vibratory motion felt on some of the more recent railroad and other bridges, and in a consequent disposition in the frame to work loose at the joints and sag.

605. The following Table contains the principal dimensions of some of the most celebrated American and European wooden bridges.

NAME, ETC. OF BRIDGE.	Number of bays.	Width of widest bay.	Rise or depth of rib.
Bridge of Schaffhausen, (A)	2	193 ft.	—
Bridge of Kandel, (B)	1	166 "	—
Bridge of Bamberg, (C)	1	208 "	16.9 ft.
Bridge of Freysingen, (C)	2	153 "	11.6 "
Essex bridge, (D)	1	250 "	—
Upper Schuylkill bridge, (E)	1	340 "	20 "
Market-street bridge, (F)	3	195 "	12 "
Trenton bridge, (G)	5	200 "	27 "
Columbia bridge, (H)	29	200 "	—
Richmond bridge, (I)	19	153 "	15.4 "
Springfield bridge, (K)	7	180 "	18 "

(A) This celebrated Swiss bridge, built by John Ulrich Grubenmann, a carpenter, consisted of two bays, the one 193 and the other 172 feet. The bridge-frame was formed of two ribs with a roadway between them. Each rib was framed, in some respects, on the same principle as an open-built beam, the upper string being supported by a number of inclined struts which rested against the abutments and pier, and the lower string, upon which the roadway timbers were laid, being suspended from the upper by suspension pieces. The whole structure was consolidated and braced by bolts, stays, and straps of iron. Remarkable in its day, yet the drawings extant of the bridge of Schaffhausen, while they attest the ingenuity and practical skill of the builder, present it in singular contrast with the equally bold and less complicated structures of the like nature recently erected in the United States.

(B) This is also a Swiss bridge, built over the torrent of Kandel in the canton of Berne. Its ribs are formed of solid-built beams which gradually decrease in depth from the centre to the extremities; this decrease being made by offsets, the built beams presenting the appearance of a number of straining beams placed below each other, against the ends of which abut inclined struts that rest against the faces of the abutments. The roadway rests upon the built beams.

(C) These two bridges are selected from among a number of the like character constructed in various parts of Germany by Wiebeking. The bridge-frame in all of them consists of several ribs of curved solid-built beams upon which the roadway timbers are laid. This method of constructing bridge-frames combines great strength and stiffness. It is more expensive than frames of straight timber, as it requires a larger amount of iron, and more complicated mechanical means for its construction than the latter, and the ribs, although stiffer, are impaired in strength by the operation of bending them.

(D) This is a very remarkable structure built over the river Merrimack near Newburyport. The ribs consist of curved open-built beams, each of which is composed of three concentric solid-built beams, connected, at intervals along the rib, by two radial pieces of hard wood which fit into mortises made through the centre of each solid beam, and by a long wedge of hard wood inserted, in the direction of the radius of curvature, between each pair of radial pieces. Each of the solid-built beams of the rib is formed of two thicknesses of scantling, about 12 or 15 feet in length, which abut end to end, breaking joints, and are connected by keys of hard wood inserted into mortises made through the two thicknesses. By these arrangements the architect has sought to preserve both the curved shape and the parallelism of the solid

beams forming the rib, and also to connect all the parts firmly. The combination is an ingenious attempt at constructing an arch of wood on similar principles to one of stone, but is inferior to the more simple and usual methods of forming curved open-built beams by using radial and diagonal pieces.

(E) This bridge, designed and built by L. Wernwag, has the widest span on record. The bridge-frame (Fig. 132) consists

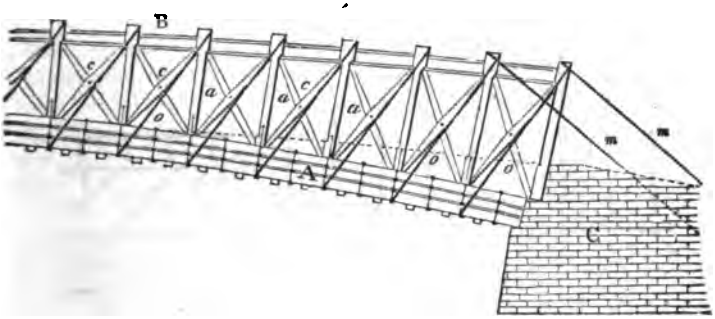


Fig. 132—Represents a side view of a portion of the open curved rib of the bridge over the Schuylkill at Philadelphia.
A, lower curved solid beam.
B, top beam.
a, *a*, posts.
c, *c*, diagonal braces.
o, *o*, iron diagonal ties.
m, *m*, iron stays anchored in the abutment C.

of five ribs. Each rib is an open-built beam formed of a bottom, curved solid-built beam and of a single top beam, which are connected by radial pieces, diagonal braces, and inclined iron stays. The bottom curved beam is composed of three concentric solid-built beams slightly separated from each other, each of which has seven courses of curved scantling in it, each course 6 inches thick by 13 inches in breadth; the courses, as well as the concentric beams, being firmly united by iron bolts, &c. A road way that rests upon the bottom curved ribs is left on each side of the centre rib, and a footpath between each of the two exterior ribs. The bridge was covered in by a roof and a sheathing on the sides.

(F) This is also one of the many bridges designed and built by Wernwag in the States of Pennsylvania and New Jersey. The bridge-frame consists of three ribs placed so far apart as to leave space between them for a carriage-way and a footpath on each side of the centre rib. Each rib is an open-built beam, consisting of a bottom curved solid-built beam, with mortises at intervals to receive radial pieces, which are connected at top by a single beam, also mortised to receive tenons on the heads of the radial pieces. A single diagonal brace is placed between each

pair of radial pieces. Longitudinal beams reach from the crown of the curved rib of one bay to that of the next, and on these the roadway-bearers are laid transversely.

(G) In this fine structure, the roadway-bearers are suspended from curved solid-built beams by iron-bar chains and suspension rods. The span of the centre bay is 200 feet, that of the two adjacent 180 feet, and that of the extreme bays 160 feet. The bridge-frame (Fig. 133) consists of five ribs, having the same

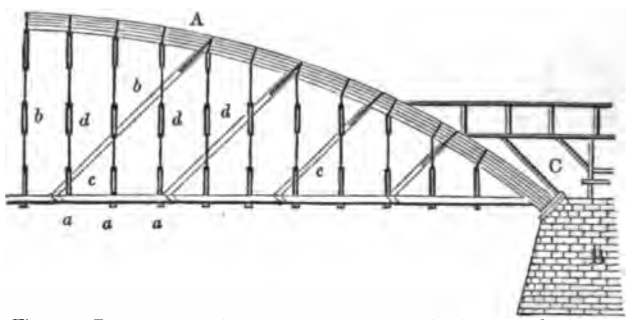


Fig. 133—Represents a side view of a portion of a rib of Trenton bridge.
A, solid curved beam.
a, a, a, cross girders suspended from A by the iron chains *b, b*.
c, c, roadway-bearers.
d, d, diagonal braces.
B, portion of pier.
C, frame work of roof-covering over the piers.

arrangement for the roadway and footpaths as in the upper Schuylkill bridge. Each of the central ribs is formed of 8 courses of curved scantling, each course being 4 inches thick, and 13 inches broad. The two exterior ribs have 9 courses of scantling of the same dimensions. Inclined timber braces connect the curved beam and roadway timbers. The ribs are tied at top by cross pieces, and stiffened by diagonal braces. The bridge-frame is braced on the exterior by vertical and horizontal timber-stays which abut against the top of the piers. The roadway is of plank laid upon longitudinal joists that rest on the roadway bearers. The roadway-bearers are stiffened by diagonal braces The abutments and piers are of stone, the latter being 20 feet thick at the impost.

(H) This, like most of the more recent bridges for railroads, aqueducts, &c., in Pennsylvania, is built upon Burr's plan, which (Fig. 134) consists in forming each rib of an open-built beam of straight timber, and connecting with it a curved solid-built beam, formed of two or more thicknesses of scantling, between which the frame-work of the open-built beam is clamped. The open-built beam consists of a horizontal bottom beam of two thicknesses of scantling, termed the *chords*, which clamp uprights, termed the

queen posts, between them,—of a single top beam, termed *the plate of the side frame*, which rests upon the uprights, with which it is

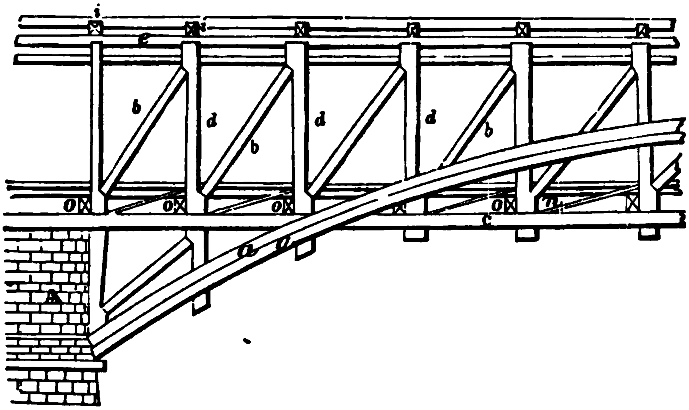


Fig. 134—Represents a side view of a portion of a rib of Burr's bridge.
a, *a*, arch timbers.
d, *d*, queen-posts.
b, *b*, braces.
c, *c*, chords.
e, *e*, plate of the side frame.
o, *o*, floor girders on which the flooring joists and flooring boards rest.
n, *n*, check braces.
i, *i*, tie beams of roof.
A, portion of pier.

connected by a mortise and tenon joint,—and of diagonal braces and other smaller braces, termed *check braces*, placed between the uprights. The curved-built beam, termed the *arch-timbers*, is bolted upon the timbers of the open-built beam. The bridge-frame may consist of two or more ribs, which are connected and stiffened by cross ties and diagonal braces. The roadway-flooring (Fig. 135) is laid upon cross pieces, termed the *floor girders*, which may either rest upon the chords, or else be attached at any intermediate point between them and the top beam. The road way and footpaths may be placed in any position between the several ribs.

There is great similarity between the combination adopted by Burr and those of the two bridge-frames just described. The main difference consists in the application by Burr of what he terms the arch-timbers, to strengthen and stiffen an open-built beam. It may be remarked from the Figs. 134, 135, that the framing of the open-built beam is faulty, in that the top beam, or plate, is not only of less dimensions than the bottom beam, or chord, but is weakened by mortises, and moreover affords no other support to the queen posts, or uprights, which act as suspension pieces for the chord, than that of the pin which confines the tenon in the mortise. From the manner in which the arch-timbers are formed and connected with the parts of the open-built

beam, they add but little if any more strength and stiffness th would be given by straight timbers reaching from the springing point of the arch timbers to their crown; and they are certainly

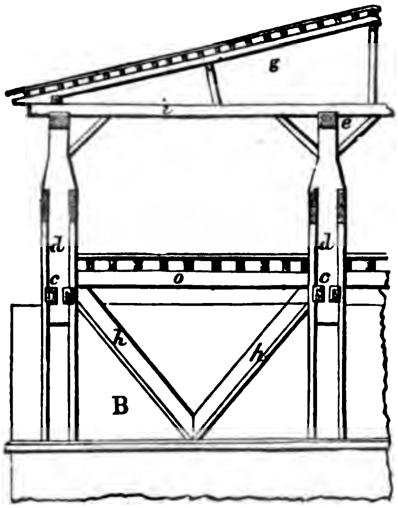


Fig. 135—Represents the half of a cross section of Fig. 134 through the crown of the arch timbers, in which the letters designate the same parts as in the preceding Fig.
g, rafters of roof truss.
h, *h*, diagonal braces of bridge frame.
B, side view of the pier.

less efficacious in subserving their end than would be inclined struts, occupying a like position at bottom, and abutting against a straining beam, placed either under the centre part of the chord, where the locality would permit it, or under the centre portion of the plate. In localities where fine timber is less abundant than in those in which the most of Burr's bridges have been built, a judicious regard to economy would undoubtedly have suggested a selection of forms for the secondary parts of the frame, which would have prevented these parts from being as much cut to waste as the Figs. show they must have been in the example taken to illustrate this system.

(I) This structure, constructed under the superintendence of Moncure Robinson, Esq., is upon Town's plan. The width of the bays varies from 130 to 153 feet. It consists of two ribs, each of which is formed of a double lattice, with two chords at bottom and one at top. The roadway, for rails, rests on the top girders. The ribs are braced by vertical diagonal braces, and by horizontal diagonal braces between each pair of the top and bottom girders. The piers are of rustic work; they are 40 feet above the low-water level, and 4 feet thick at top. The example here selected for illustration (Fig. 136) is taken from another bridge, of nearly the same width of bay, erected subsequently to the Richmond bridge, by the same engineer, in which the top

chord also is doubled, as the former bridge was found to be rather weak.

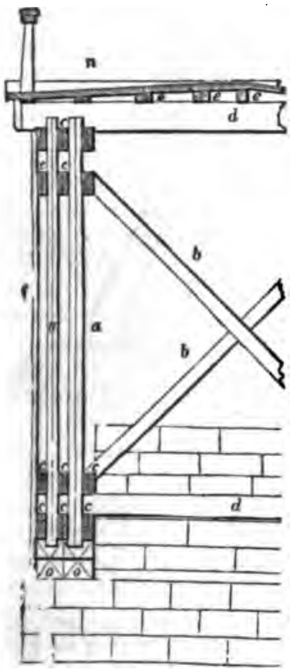


Fig. 136—Represents a cross section of a railroad bridge with Town's truss, in which the rails of the road are placed on a flooring on the top of the truss.
a, a, double lattice.
c, c, top and bottom chords doubled.
b, b, vertical diagonal braces of the two ribs.
d, d, top and bottom girders.
e, e, flooring joists.
n, cross bearers of the rails.
o, o, corbels or support timbers on the piers on which the ribs rest.
f, sheathing, or weather-boarding.

(K) This bridge is constructed on Howe's plan. It consists (Fig. 137) of two ribs which are connected at top and bottom, in the usual manner, with cross ties and diagonal braces. The roadway flooring rests upon the cross girders at bottom. The bridge is not roofed, as is usually the case, the ribs being covered in on the sides and at top by a sheathing of boards, and the flooring-boards by a metallic covering.

The bridges constructed according to Colonel Long's plan have been mostly applied to medium spans. In the printed description of the different improvements of this system patented by Colonel Long, he very judiciously introduces struts, which he terms *arch braces*, either below the top or the bottom string, as the locality may demand, for the purpose of preventing sagging, which must necessarily take place in time in all open-built beams of considerable span, if not strengthened in this way.

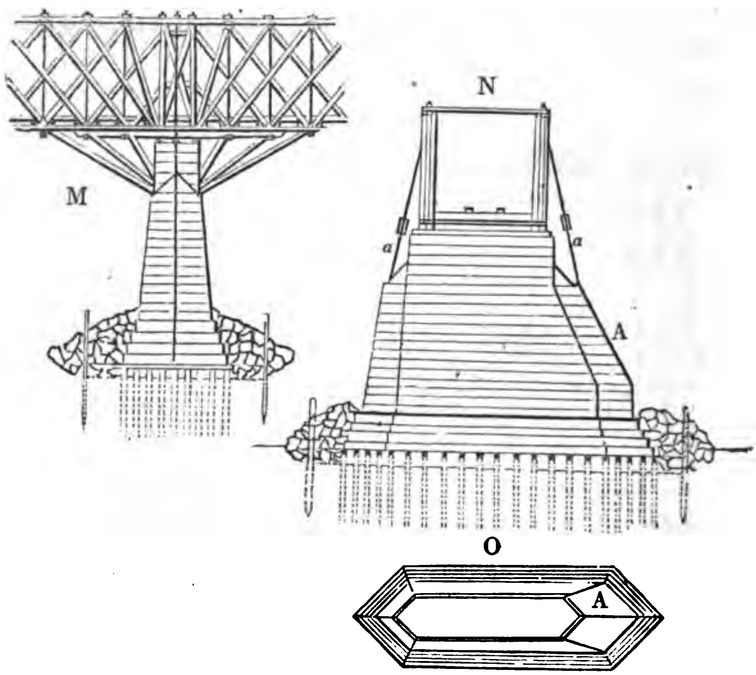


Fig. 137—Represents a side view of the truss and an end view of the pier, M; a cross section of the truss and side view of the pier, N; and a top view O, of the pier of the railroad bridge at Springfield.
A, inclined plane of the ice-breaker of the up-stream starling.
a, *a*, iron side-stays of the ribs anchored into the piers at top.

CAST-IRON BRIDGES

606. Bridges of cast iron admit of even greater boldness of design than those of timber, owing to the superiority, both in strength and durability, of the former over the latter material; and they may therefore be resorted to under circumstances very nearly the same in which a wooden structure would be suitable.

607. The abutments and piers of cast-iron bridges should be built of stone, as the corrosive action of salt water, or even of fresh water when impure, would in time render iron supports of this character insecure; and timber, when exposed to the same destructive agents, is still less durable than cast iron.

The forms and dimensions of the stone abutments and piers are regulated on the same principles as the like parts in wooden bridges with curved frames. The piers may be either built up high enough to receive the roadway-bearers, or else they may be terminated just above the springing plates of the bridge-frame

and form supports for cast-iron standards upon which the roadway bearers may be laid.

608. The curved ribs of cast-iron bridge-frames have undergone various modifications and improvements. In the earliest bridges, they were formed of several concentric arcs, or curved beams, placed at some distance asunder, and united by radial pieces; the spandrels being filled either by contiguous rings, or by vertical pieces of cast iron upon which the roadway bearers were laid.

In the next stage of progress towards improvement, the curved ribs were made less deep, and were each formed of several segments, or panels cast separately in one piece, each panel consisting of three concentric arcs connected by radial pieces, and having flanches, with other suitable arrangements, for connecting them firmly by wrought-iron keys, screw-bolts, &c.; the entire rib thus presenting the appearance of three concentric arcs connected by radial pieces. The spandrels were filled either with panels formed like those of the curved ribs, with iron rings, or with a lozenge-shaped reticulated combination. The ribs were connected by cast-iron plates and wrought-iron diagonal ties.

In the more recent structures, the ribs have been composed of voussoir-shaped panels, each formed of a solid thin plate with flanches around the edges; or else of a curved tubular rib, formed like those of Polonceau, or of Delafield, described under the head of Framing. The spandrel-filling is either a reticulated combination, or one of contiguous iron rings. The ribs are usually united by cast-iron tie-plates, and braced by diagonal ties of cast and wrought iron.

609. The roadway-bearers and flooring may be formed either of timber, or of cast iron. In the more recent structures in England, they have been made of the latter material; the roadway-bearers being cast of a suitable form for strength, and for their connection with the ribs; and the flooring-plates being of cast iron.

The roadway and footpaths, formed in the usual manner, rest upon the flooring-plates.

The parapet consists, in most cases, of a light combination of cast or wrought iron, in keeping with the general style of the structure.

610. The English engineers have taken the lead in this branch of architecture, and, in their more recent structures, have carried it to a high degree of mechanical perfection and architectural elegance. Among the more celebrated cast-iron bridges in England, that of *Coalbrookdale* belongs to the first epoch above mentioned; those of *Staines* and *Sunderland* to the second; and to the third, the bridge of *Southwark* at London; that of *Tewkes*

bury over the Severn; that over the Lary near Plymouth, and a number of others in various parts of the United Kingdom.

The French engineers have not only followed the lead set them by the English, but have taken a new step, in the tubular-shaped ribs of M. Polonceau. The *Pont des Arts* at Paris, a very ligh bridge for foot-passengers only, and which is a combination ol cast and wrought iron, belongs to their earliest essays in this line; the *Pont d'Austerlitz*, also at Paris, which is a combination similar to those of Staines and Sunderland, belongs to their second epoch; and the *Pont du Carrousel*, in the same city, built upon Polonceau's system, with several others on the same plan, belong to the last.

In the United States a commencement can hardly be said to have been made in this branch of bridge architecture; the bridge of eighty feet span, with tubular ribs, constructed by Major Delafield at Brownsville, stands almost alone, and is a step contemporary with that of Polonceau in France.

The following Table contains a summary description of some of the most noted European cast-iron bridges.

NAME OF BRIDGE.	River.	Numb. of arches.	Span in feet.	Rise in feet.	Numb. of ribs.	Date.	Engineer.
Coalbrookdale, (A)	Severn.	1	100.5	40	5	1779	—
Wearmouth, (B)	Wear.	1	240	30	6	1796	Burdon.
Staines, (C)	—	1	181	16.5	-	1802	—
Austerlitz, (D)	Seine.	5	106.6	10.6	7	1805	Lamandé.
Vauxhall, (E)	Thames.	9	78	-	9	1816	Walker.
Southwark, (F)	Thames.	3	240	24	8	1818	Rennie.
Tewkesbury, (G)	Severn.	1	170	17	6	-	Telford.
Lary. (H)	Lary.	5	100	14.5	5	1827	Rendel.
Carrousel, (I)	Seine.	3	150	16	5	1838	Polonceau.

(A) This is the first cast-iron bridge erected in England. The curved rib is nearly a semicircle in shape, and is composed of three concentric arcs, which are connected at intervals by short columnar pieces, in the direction of the radii of the curve.

(B) This structure, which connects Wearmouth and Sunderland, has a remarkably bold appearance, both from its great span, and its height, which is 100 feet between the high water-level and the intrados of the arch at the crown. The entire rib presents the appearance of an open-built beam, composed of three concentric arcs united by radial pieces. The spandrel-filling is formed of contiguous iron rings, of increasing diameters from the crown to the springing line, which rest upon the back of the curved rib, and support the roadway-bearers.

(C) Staines bridge was designed on the same plan as Wearmouth; but from a defect in the strength of its abutments, they successively yielded to the horizontal thrust, which in so flat an arch was very considerable.

(D) The bridge of Austerlitz is constructed on the same prin ciple as the two last, and produces a light and pleasing architectural effect. Each curved rib consists of 21 voussoir-shaped panels, about 4 feet in depth. The spandrel-fillings present the appearance of a continuation of the curved rib outwards, to form a support for the roadway-bearers. The piers are terminated at the springing lines of the curved rib, and are at this point 13 feet thick; the roadway above them being supported by the ribs con tinued up to its level. The roadway is on a level, the roadway bearers and flooring being of timber.

(E) In this structure the curved rib is formed of solid panels The spandrel-fillings consist of vertical shafts united by cross pieces. The piers are built up to support the roadway-bearers; they are 13 feet thick at the springing line. The entire width of the bridge is 36 feet, the carriage-way occupying 25 feet.

(F) In this bold structure, the width of each of the two extreme bays is 210 feet. The curved rib is composed of thirteen solid panels, each of which is 2¾ inches thick, and has a rim, or flanch around it about 4 inches broad. The rib is 6 feet deep at the crown and 8 feet at the spring. The spandrel-filling is composed of lozenge-shaped panels with vertical joints; they are secured to the back of the curved rib and support the roadway-plates. The curved ribs are connected by tie-plates inserted between the joints of the voussoirs; and they are braced by feathered diagonal braces. The piers are 24 feet thick at the springing line, and are built up to the level of the roadway-plates. The width of the carriage-way is 25 feet, and that of each of the footpaths 7 feet.

(G) This bridge presents a very light and elegant appearance; the panels of the curved rib being cast with open curvilinear spaces, which divide the panel into several rectangular-shaped figures, with solid sides and diagonals. Each rib consists of twelve panels. The depth of the ribs is 3 feet. The thickness of the two exterior ribs is 2½ inches, that of the four interior 2 inches. The ribs are connected by grated tie-plates between the panel-joints, and they abut against springing plates which are 3 feet wide and 4 inches thick. The roadway-bearers and road-plates are of cast iron. The spandrel-filling is composed of lozenge-shaped panels, the sides of the lozenges being feathered, and tapering from the middle to the extremities. The ribs of the bridge-frame are connected and braced in the usual manner. The road-bearers are laid lengthwise upon the ribs, to which they are firmly secured, and they are covered with iron road-plates, upon which the road-covering rests. The free road space is 24 feet.

(H) In this structure, (Figs. 138, 139,) the engineer has de

parted from the usual form of a circular segment arch and adopted an elliptical segment. The following summary description

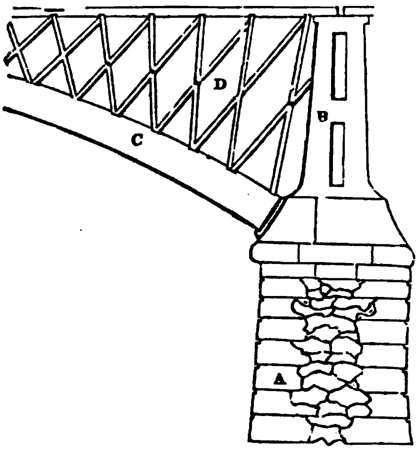


Fig. 138—Represents a longitudinal section through a pier and its cast iron standard of Lary bridge, showing the connection of the cast-iron framing and the stone piers.
A, upper portion of pier
B, standard.
C, panel of the curved rib.
D, lozenge spandrel-filling.

tion is extracted from the engineer's published account of this work:—"The arrangement of the design differs materially from other works of a similar nature: first, in the masonry of the piers

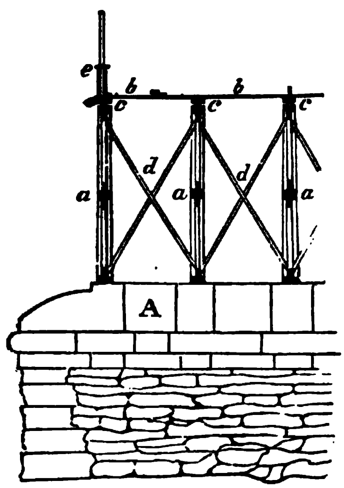


Fig. 139—Represents a cross section of Fig 138 taken through the axis of the pier.
A, portion of pier.
a, a, iron standards.
b, b, road-plates laid on the roadway-bearers c, c.
d, d, diagonal braces of the standards.
e, roadway-skirting forming the base of the parapet.

finishing at the springing course of the arches; secondly, in the curvilinear forms of the piers and abutments; and thirdly, in the employment of elliptical arches.

"The centre arch is 100 feet span, and rises 14 feet 6 inches,

the thickness of the piers, where smallest, being 10 feet. The arches adjoining the centre are 95 feet span each, and rise 13 feet 3 inches. The piers, taken as before, are each 9 feet 6 inches thick. The extreme arches are each 81 feet span, and rise 10 feet 6 inches. The abutments are, in their smallest dimensions, 13 feet thick, forming at the back a strong arch abutting against the return-walls to resist the horizontal thrust. The ends of the piers are semicircular, having a curvilinear batter on the sides and ends formed with a radius of 35 feet, and extending upward from the level of high water to the springing course, and downward to the level of the water at the lowest ebb. The front of the abutments have a corresponding batter.

"The roadway is 24 feet wide, supported by 5 cast-iron equidistant ribs. Each rib is 2 feet 6 inches in depth at the springing, and 2 feet at the apex, by 2 inches thick, with a top and bottom flange of 6 inches wide by 2 inches thick, and is cast in 5 pieces; their joints (which are flanged for the purpose) are connected by screw-pins with tie-plates equal in length to the width of the roadway, and in depth and thickness to the ribs; between these meeting-plates the ribs are connected by strong feathered crosses, or diagonal braces, with screw-pins passing through their flanges and the main ribs. The springing-plates are 3 inches thick, with raised grooves to receive the ends of the ribs, which have double shoulders. These plates are sunk flush into the springing course of the piers and abutments, which, with the cordon and springing course, are of granite. The pier-standards and spandrel-fillings are feathered castings, connected transversely by diagonal braces and wrought-iron bars passing through cast-iron pipes, with bearing-shoulders for the several parts to abut against. The roadway-bearers are 7 inches in depth by 1¼ thick, with a proportional top and bottom flange; they are fastened to the pier-standards by screw-pins through sliding mortises, whereby a due provision is made for either expansion or contraction of the metal; the roadway-plates are ¾ of an inch thick by 3 feet wide, connected by flanges and screw-pins, and project 1 foot over the outer roadway-bearers, thus forming a cornice the whole length of the bridge.

"The adoption of these forms for the piers and arches, in unison with the plan of finishing the piers above the springing course with cast iron instead of masonry, has, as I had hoped, given a degree of uniform lightness combined with strength to the general effect, unobtainable by the usual form of straight-sided piers carried to the height of the roadway, with flat segments of a circle for the arches."

(I) The curved ribs of this bridge are tubular, the cross section of the tube being an ellipse, the transverse axis of which is

2 feet 6 inches, and the conjugate about 1 foot 4 inches. Each rib consists of eleven pieces, which are shaped and connected as described under the head of Framing. The spandrel-fillings are formed of contiguous cast-iron rings which rest upon the ribs, and support the longitudinal roadway-bearers. The ribs are tied and braced nearly in the usual manner. The flooring upon which the road-covering is laid is of timber. The piers are built up to receive the roadway-bearers.

The system of M. Polonceau presents a very light and elegant form of cast-iron bridge. The inventor claims for it more economy than by the ordinary combinations, and also more lightness combined with adequate strength. It has been objected to this system that it is defective in rigidity; this the inventor seems disposed to regard as an advantage, and has preferred the spandrel-filling of rings partly on this account, because their elasticity is favorable to a gradual yielding and restoration of form in the parts.

611. *Effects of Temperature on stone and cast-iron Bridges* The action of variations of temperature upon masses of masonry, particularly in the coping, has already been noticed. The effect of the same action upon the equilibrium of arches was first observed by M. Vicat in the stone bridge built by him at Souillac, in the joints of which periodical changes were found to take place, not only from the ranges of temperature between the seasons, but even daily. Similar phenomena were also very accurately noted by Mr. George Rennie in a stone bridge at Staines.

From these recorded observations the fact is conclusively established, that the joints of stone bridges, both in the arches and spandrels, are periodically affected by this action, which must consequently at times throw an increased amount of pressure upon the abutments, but without, under ordinary circumstances, any danger to the permanent stability of the structure.

When iron was first proposed to be employed for bridges, objections were brought against it on the ground of the effect of changes of temperature upon this metal. The failure in the abutments of the iron bridge at Staines was imputed to this cause, and like objections were seriously urged against other structures about to be erected in England. To put this matter at rest, observations were very carefully made by Sir John Rennie upon the arches of Southwark bridge, built by his father. From these experiments it appears that the mean rise of the centre arch at the crown was about $\frac{1}{40}$th of an inch for each degree of Fahr., or 1.25 inches for 50° Fahr. The change of form and increase of pressure arising from this cause do not appear to have affected in any sensible degree the permanent stability either of this structure, or of any of a like character in Europe.

SUSPENSION BRIDGES.

612. The use of flexible materials, as cordage and the like, to form a roadway over chasms, and narrow water-courses, dates from a very early period; and structures of this character were probably among the first rude attempts of ingenuity, before the arts of the carpenter and mason were sufficiently advanced to be made subservient to the same ends. The idea of a suspended roadway, in its simplest form, is one that would naturally present itself to the mind, and its consequent construction would demand only obvious means and but little mechanical contrivance; but the step from this stage to the one in which such structures are now found, supposes a very advanced state both of science and of its application to the industrial arts, and we accordingly find that bridge architecture, under every other guise, was brought to a high degree of perfection before the suspension bridge, as this structure is now understood, was attempted.

With the exception of some isolated cases which, but in the material employed, differed little from the first rude structures, no recorded attempt had been made to reduce to systematic rules the means of suspending a roadway now in use, until about the year 1801, when a patent was taken out in this country for the purpose, by Mr. Finlay, in which the manner of hanging the chain supports, and suspending the roadway from it, are specifically laid down, differing, in no very material point, from the practice of the present day in this branch of bridge architecture. Since then, a number of structures of this character have been erected both in the United States and in Europe, and, in some instances, valleys and water-courses have been spanned by them under circumstances which would have baffled the engineer's art in the employment of any other means.

A suspension bridge consists of the supports, termed *piers*, from which the suspension chains are hung; of the anchoring masses, termed the *abutments*, to which the ends of the suspension chains are attached; of the suspension chains, termed the *main chains*, from which the roadway is suspended; of the vertical rods, or chains, termed the *suspending-chains*, &c., which connect the roadway with the main chains; and of the roadway.

613. As the general principles upon which flexible supports for structures should be arranged have already been laid down under the head of Framing, nothing more will be requisite, under the present head, than to add those modifications of the applications of these principles called for by the character of the structures in question.

614. *Bays.* The natural water-way may be divided into any number of equal-sized bays, depending on local circumstance

and the comparative cost of high or low piers, and that of the main chains, and the suspending-rods.

A bridge with a single bay of considerable width presents a bolder and more monumental character, and its stability, all other things being equal, is greater, the amplitude from undulations caused by a moveable load being less than one of several bays.

If two bays of equal span are preferred to a single one with an equal versed sine, the chains may be supported either by a single central pier, or by three piers of the same height. With a single pier, the structure will present the appearance (Fig. 101. Art. 538) of two half curves. The tension on the chains and the horizontal strain at the top of the pier will, in this case, be the same as in that of the full curve of double the span and the same versed sine; and twice as great as in the case of three piers with curves of equal span and the same versed sine.

If, instead of a central pier with two semi-arches, two entire arches be preferred for the bridge, then three piers will be necessary, which need only be half the height of those which a single bay would require. The tension on the chains in this case will be only one fourth of that upon the chains of a bridge with a single bay of double width; and the abutments may be made proportionally less strong.

615. *Piers*. These are commonly masses of masonry in the shape of pillars, or columns, that rest on a common foundation, and are usually connected at top. The form given to the pier, when of stone, will depend in some respects on the locality. Generally it is that of the architectural monument known as the *Triumphal Arch;* an arched opening being formed in the centre of the mass for the roadway, and sometimes two others of smaller dimensions, on each side of the main one, for approaches to the footpaths of the bridge.

Piers of a columnar, or of an obelisk form, have in some instances been tried. They have generally been found to be wanting in stiffness, being subject to vibrations from the action of the chains upon them, which in turn, from the reciprocal action upon the chains, tends very much to increase the amplitude of the vibrations of the latter. These effects have been observed to be the more sensible as the columnar piers are the higher and more slender.

Cast-iron piers, in the form of columns connected at top by an entablature, have been tried with success, as also have been columnar piers of the same material so arranged, with a joint at their base, that they can receive a pendulous motion at top to accommodate any increase of tension upon either branch of the chain resting on them.

The dimensions of piers will depend upon their height and the

strain upon them. When built of stone, the masonry should be very carefully constructed of large blocks well bonded, and tied by metal cramps. The height of the piers will depend mostly on the locality. When of the usual forms, they should at least be high enough to admit the passage of vehicles under the arched way of the road.

616. *Abutments.* The forms and dimensions of the abutments will depend upon the manner in which they may be connected with the chains. When the locality will admit the chains to be anchored without deflecting them vertically, the abutments may be formed of any heavy mass of rough masonry, which, from its weight, and the manner in which it is imbedded, have sufficient strength to resist the tension in the direction of the chain. If it is found necessary to deflect the chains vertically to secure a good anchoring point, it will also generally be necessary to build a mass of masonry of an arched form at the point where the deflection takes place, which, to present sufficient strength to resist the pressure caused by the resultant of the tension on the two branches of the chain, should be made of heavy blocks of cut stone well bonded. If the abutments are not too far from the foundations of the piers, it will be well to connect the two, in order to give additional resistance to the anchoring points.

617. *Main Chains,* &c. The suspending curves, or arches, may be made of chains formed of flat, or round iron, or may consist of wire cables constructed in the usual manner.

The main chains of the earlier suspension bridges were formed of long links of round iron made in the usual way; but, independently of the greater expense of these chains, they were found to be liable to defects of welding, and the links, when long, were apt to become misshapen under a great strain, and required to be stayed to preserve their form. Chains formed of long links of flat bars, usually connected by shorter ones, as coupling links, have on these accounts superseded those of the ordinary oval-shaped links.

The breadth of the chains has generally been made uniform, but in some recent bridges erected in England by Mr. Dredge, the chains are made to increase uniformly in breadth, by increasing the number of bars in a link, from the centre to the points of suspension. In addition to this change in the form of the main chains, Mr. Dredge places the suspending chains in a vertical plane parallel to the axis of the bridge, but obliquely to the horizon, inclining each way from the points of suspension towards the centre of the curve. From experiments, it appears that a very considerable increase of strength, for the same amount of material, is given by these modifications.

The number and disposition of the chains will depend upon the

strain to be borne and the arrangement of the roadway and foot paths. For a single carriage-way the main chains are disposed on each side, leaving the requisite width of the carriage-way between them. Should the weight to be borne be so great that the number of bars in a link would give such breadth to the chain as to require a considerable addition to the breadth of the piers, two or more chains must be employed, and these should be suspended one immediately below the other. It has been suggested that their distance apart should be such that the shadow from the chain above upon that beneath should not prevent the action of the sun's rays, in evaporating any moisture that may lodge in the articulations of the links, and also to preserve an equable temperature in all the chains. If there are two carriage-ways, with footpaths, any arrangement of the chains may be adopted, similar to those already pointed out for the ribs of wooden bridges under like circumstances; care being taken that the strength of the chains be proportioned to the strain upon them, and that they be placed so far asunder, that in violent oscillations from high winds they may not come into collision.

Some of the links of the main chains should be arranged with adjusting screws, or with keys, to bring the chains to the proper degree of curvature when set up.

The chains may either be attached to, or pass over a moveable cast-iron saddle, seated on rollers on the top of the piers, so that it will allow of sufficient horizontal displacement to permit the chains to accommodate themselves to the effects of a moveable load on the roadway. The same ends may be attained by attaching the chains to a pendulum bar suspended from the top of the pier.

The chains are firmly connected with the abutments, by being attached to anchoring masses of cast iron, arranged in a suitable manner to receive and secure the ends of the chains, which are carefully imbedded in the masonry of the abutments. These points, when under ground, should be so placed that they can be visited and examined from time to time.

618. *Suspending Chains.* The suspending-rods, or chains, should be attached to such points of the main chains and the roadway-bearers, as to distribute the load uniformly over the main chains, and to prevent their being broken or twisted off by the oscillations of the bridge from winds, or moveable loads. They should be connected by suitably-arranged articulations, with a saddle piece bearing upon the back of the main chain, and at bottom with the stirrup that embraces the roadway-bearers.

The suspending-chains are usually hung vertically. In some recent bridges they have been inclined inward to give more stiffness to the system.

619. *Roadway.* Transversal roadway-bearers are attached to the suspending-chains, upon which a flooring of timber is laid for the roadway. The roadway-bearers, in some instances, have been made of wrought iron, but timber is now generally preferred for these pieces. Diagonal ties of wrought iron are placed hori zontally between the roadway-bearers to brace the frame-work.

The parapet may be formed in the usual style either of wrought iron, or of timber, or of a combination of cast iron and timber Timber alone, or in combination with cast iron, is now preferred for the parapets; as observation has shown that the stiffness given to the roadway by a strongly-trussed timber parapet limits the amplitude of the undulations caused by violent winds, and secures the structure from danger

In some of the more recent suspension bridges, a trussed frame, similar to the parapet, has been continued below the level of the roadway, for the purpose of giving greater security to the structure against the action of high winds.

When the roadway is above the chains, any requisite number of single chains may be placed for its support. Frames formed of vertical beams of timber, or of columns of cast iron united by diagonal braces, rest upon the chains, and support the roadway-bearers placed either transversely, or longitudinally.

620. *Vibrations.* The undulatory or vibratory motions of suspension bridges, caused by the action of high winds, or moveable loads, should be reduced to the smallest practicable amount, by a suitable arrangement of bracing for the roadway-timbers and parapet, and by chain-stays attached to the roadway and to the basements of the piers, or to fixed points on the banks whenever they can be obtained.

Calculation and experience show that the vibrations caused by a moveable load decrease in amplitude as the span increases, and, for the same span, as the versed sine decreases. The heavier the roadway, also, all other things being the same, the smaller will be the amplitude of the vibrations caused by a moveable load, and the less will be their effect in changing the form of the bridge.

The vibrations caused by a moveable load seldom affect the bridge in a hurtful degree, owing to the elasticity of the system, unless they recur periodically, as in the passage of a body of soldiers with a cadenced march. Serious accidents have been occasioned in this way; also by the passage of cattle, and by the sudden rush of a crowd from one side of the bridge to the other. Injuries of this character can only be guarded against by a proper system of police regulations.

Chain-stays may either be attached to some point of the road way. and to fixed points beneath it, or else they may be in the

form of a reversed curve below the roadway. The former is the more efficacious, but it causes the bridge to bend in a disagreeable manner at the point where the stay is attached, when the action of a moveable load causes the main chains to rise. The more oblique the stays, the longer, more expensive, and less effective they become. Stays in the form of a reversed curve preserve better the shape of the roadway under the action of a moveable load, but they are less effective in preventing vibrations than the simple stay. Neither of these methods is very serviceable, except in narrow spans. In wide spans, variations of temperature cause considerable changes in the length of the stays, which makes them act unequally upon the roadway; this is particularly the case with the reversed curve. Both kinds should be arranged with adjusting screws, to accommodate their length to the more extreme variations of temperature.

Engineers, at present, generally agree that the most efficacious means of limiting the amplitude, and the consequent injurious effects of undulations, consists in a strong combination of the roadway-timbers and flooring, stiffened by a trussed parapet of timber above the roadway, and in some cases in extending the frame-work of the parapet below it. These combinations present, in appearance, and reality, two or more open-built beams, as circumstances may demand, placed parallel to each other, and strongly connected and braced by the frame-work of the roadway, which are supported at intermediate points by the suspending-rods, or chains. The method of placing the roadway-framing at the central line of the open-built beams presents the advantage of introducing vertical diagonal braces, or ties between the beams beneath the roadway-frame. The main objection to these combinations is the increased tension thrown upon the chains from the greater weight of the frame-work. This increase of tension, however, provided it be kept within proper limits, so far from being injurious, adds to the stability and security of the bridge, both from the effects of undulations and of vibrations from shocks

As a farther security to the stability of the structure, the frame work of the roadway should be firmly attached at the two extremities to the basements of the piers.

621. *Preservative means.* To preserve the chains from oxidation on the surface, and from rain or dews which may lodge in the articulations, they should receive several coats of minium or of some other preparation impervious to water, and this should be renewed from time to time, and the forms of all the parts should be the most suitable to allow the free escape of moisture.

Wires for cables can be preserved from oxidation, until they are made into ropes, by keeping them immersed in some alkaline solution. Before making them into ropes they should be dipped

several times in boiling linseed oil, prepared by previously boiling it with a small portion of litharge and lampblack. The cables should receive a thick coating of the same preparation before they are put up, and finally be painted with white lead paint, both as a preservative means, and to show any incipient oxidation, as the rust will be detected by its discoloring the paint.

622. *Proofs of Suspension Bridges*. From the many grave accidents, accompanied by serious loss of life, which have taken place in suspension bridges, it is highly desirable that some trial-proof should be made before opening such bridges to the public, and that, moreover, strict police regulations should be adopted and enforced, with respect to them, to guard against the recurrence of such disasters as have several times taken place in England, from the assemblage of a crowd upon the bridge. In France, and on the continent generally, where one of the important duties of the public police is to watch over the safety of life, under such circumstances, regulations of this character are rigidly enforced. The trial-proof enacted in France for suspension bridges, before they are thrown open for travel, is about 40 lbs. to each superficial foot of roadway in addition to the permanent weight of the bridge. This proof is at first reduced to one half, in order not to injure the masonry of the points of support during the green condition of the mortar. It is made by distributing over the road surface any convenient weighty material, as bricks, pigs of iron, bags of earth, &c. Besides this after-trial, each element of the main chains should be subjected to a special proof to prevent the introduction of unsound parts into the system. This precaution will not be necessary for the wire of a cable, as the process of drawing alone is a good test. Some of the coils tested will be a guarantee for the whole.

From experiments made at Geneva by Colonel Dufour, one of the earliest and most successful constructors of suspension bridges on the Continent, it appears that wrought bar iron can sustain without danger of rupture a shock arising from a weight of 44 lbs. raised to a height of 3.28 feet on each, .0015dths of an inch of cross section, when the bar is strained by a weight equal to one third of its breaking weight; and he concludes that no apprehension need be entertained of injury to a bridge from shocks caused by the ordinary transit upon it, which has been subjected to the usual trial of a dead weight; and that the safety, in this respect, is the greater as the bridge is longer, since the elasticity of the system is the best preservative from accidents due to such causes.

623. *Durability*. Time is the true test of the durability of the structures under consideration. So far as experience goes there seems to be no reason to assign less durability to suspen

sion than to cast-iron, or even stone bridges, if their repairs and the proper means of preserving them from decay are attended to. Doubts have been expressed as to the durability of wire cables, but these seem to have been set at rest by the trials and examinations to which a bridge of this kind, erected by Colonel Dufour, at Geneva, was subjected by him after twenty years service. It was found that the undulations were greater than when the bridge was first erected, owing to the shrinking of the roadway-frame; but the main cables, and suspending-ropes, even at the loops in contact with the timber, proved to be as sound as when first put up, and free from oxidation; and the whole bridge stood another very severe proof without injury.

624. The following succinct descriptions of the principal elements of some of the most celebrated suspension bridges of chains, and wire cables, of remarkable span, are taken from various published accounts.

Bridge over the *Tweed* near *Berwick*. This is the first large suspension bridge erected in Great Britain. It was constructed upon the plans of Capt. *Brown*, who took out a patent for the principles of its construction.

Span	449 feet.
Versed sine . . .	30 "

Number of main chains 12, six being placed on each side of the roadway, in three ranges, of two chains each, above each other.

The chains are composed of long links of round iron, 2 inches in diameter, and are 15 feet long. They are connected by coupling links of round iron, 1½ inch diameter, and about 7 inches long, by means of coupling bolts.

The roadway is borne by suspending-rods of round iron, which are attached alternately to the three ranges of chains. The roadway-bearers are of timber, and are laid upon longitudinal bars of wrought iron, which are attached to the suspension rods.

Menai Bridge, erected after the designs of Mr. *Telford*. Opened in 1826.

Span	579.8 feet.
Versed sine . .	43 "

Number of main chains 16, arranged in sets of 4 each, vertically above each other.

Number of bars in each link 5.

Length of links 10 feet.

Breadth of each bar 3½ inches; depth 1 inch.

Coupling links 16 inches long, 8 inches broad, and 1 inch deep

Coupling bolts 3 inches in diameter.

Total area of cross section of the main chain, 260 square inches

The main chains are fastened to their abutments by anchoring

bolts 9 feet long and 6 inches in diameter, which are secured in cast-iron grooves. The abutments, which are underground and reached by suitable tunnels, are the solid rock.

Upon the tops of the piers are cast-iron saddles, upon which the main chains rest. The base of the saddle, which is fitted with grooves to receive them, rests upon iron rollers placed on a convex cylindrical bed of cast iron, shaped like the bottom of the base of the saddle, to admit of a slight displacement of the chains from moveable loads, or changes of temperature.

The roadway is divided into two carriage-ways, each 12 feet wide, and a footpath 4 feet wide between them. The roadway-framing consists of 444 wrought-iron roadway-bearers, 3½ inches deep and ½ inch thick, which are supported at the centre points of each of the carriage-ways by an inverted truss, consisting of two bent iron ties which support a vertical bar placed under the roadway-bars at the points just mentioned. The platform of the roadway is formed of two thicknesses of plank. The first, 3 inches thick, is laid on the roadway-bearers and fastened to them. This is covered by a coating of patent felt soaked in boiling tar. The second is two inches thick and spiked to the first.

The roadway is suspended by articulated rods attached to stirrups on the roadway-bearers and to the coupling bolts of the main chains.

The piers are 152 feet high above the high-water level. They have an arched opening leading to the roadway, and the masses on the sides of the arch are built hollow, with a cross-tie partition wall between the exterior main walls.

The parapet is of wrought-iron vertical and parallel bars connected by a network.

This bridge was seriously injured by a violent gale, which gave so great an oscillation to the main chains that they were dashed against each other, and the rivet-heads of the bolts were broken off. To provide against similar accidents, a frame-work of cast iron tubes, connected by diagonal pieces, was fastened at intervals between the main chains, by cross ties of wrought-iron rods, which passed through the tubes, and were firmly connected with the exterior chains. Subsequently to this addition, a number of strong timber roadway-bearers were fastened at intervals to those of iron, as the iron roadway-bearers were found to have been bent, and in some instances broken, by the undulatory motion of the bridge in heavy gales.

The total suspending weight of this bridge, including the main chains, roadway, and all accessories, is stated at 643 tons 15¼ cwt.

The *Fribourg bridge* of wire thrown across the valley of the

Sarine, opposite Fribourg, was erected in 1832 by *M. Chaley*, a French engineer.

Span . .	870.32 feet.
Versed sine . .	63.26 "

There are 4 main cables, two on each side of the road, of the same elevation, and about 1½ inch asunder. Each cable is composed of 1056 wires, each about 0.118 inch in diameter, which are firmly connected and brought to a cylindrical shape by a spiral wire wrapping. The diameter of the cable varies from 5 to 5¼ inches. The cables pass over 3 fixed pulleys on the top of the piers, upon which they are spread out without ligatures, and are each attached to two other cables of half their diameter which are anchored at some distance from the piers, in vertical pits, passing over a fixed pulley where they enter the mouth of the pit.

The suspending-ropes are of wire a size smaller than that used for the cables. Their diameter is nearly 1 inch. They are formed with a loop at each end, fastened around a crupper-shaped piece of cast iron, that forms an eye to connect the rope with the hook of the stirrup affixed to the roadway-bearers, and to a saddle-piece of wrought iron, for each rope, that rests on the two main cables.

The roadway-bearers are of timber, being deeper in the centre than at the two ends, the top surface being curved to conform to a slight transverse curvature given to the surface of the carriage-way; they are placed about 5 feet between their centre lines, every fourth one projecting about 3 feet beyond the ends of the others, to receive an oblique wrought-iron stay to maintain the parapet in its vertical position. The carriage-way, which is about 15½ feet wide, is formed of two thicknesses of plank. The foot-paths, which are 6 feet wide, are raised above the surface of the carriage-way, and rest upon longitudinal beams of large dimensions, the inner one of which is firmly secured to the roadway-bearers by stirrups which embrace them, and the exterior one is fastened to the same pieces by long screw-bolts, which pass through the top rail of the parapet. The roadway has a slight curvature from the centre to the two extremities, along the axis; the centre point being from 18 inches to about 3 feet higher than the ends, according to the variations of temperature. The main cables at the centre are brought down nearly in contact with the roadway-timbers.

The parapet is an open-built beam, consisting of a top rail, the bottom rail being the longitudinal exterior beam of the footpath, and of diagonal pieces which are mortised into the two rails; the whole being secured by the iron bolts that pass through the road way-bearers and the top rail. This combination of the parapet

with the inclination towards the axis of the roadway given to the suspending-ropes, gives great stiffness to the roadway, and counteracts both lateral oscillations and longitudinal undulations.

The piers consist of two pillars of solid masonry, about 66 fee high above the level of the roadway, which are united, at about 33 feet above the same level, by a full centre arch, having a span of nearly 20 feet, and which forms the top of the gateway leading to the bridge.

Hungerford and *Lambeth bridge,* erected over the Thames upon the plans of Mr. Brunel.

This bridge, designed for foot-passengers only, has the widest span of any chain bridge erected up to this period.

Span	. . .	676½ feet.
Versed sine	. .	50 "

The main chains are 4 in number, two being placed on each side of the bridge, one above the other. These chains are formed entirely of long links of flat bars; the links near the centre of the curve having alternately ten and eleven bars in each, and those near the piers alternately eleven and twelve bars. The bars are 24 feet long, 7 inches in depth, and 1 inch thick. They are connected by coupling-bolts, 4⅝ inches in diameter, which are secured at each end by cast-iron nuts, 8 inches in diameter, and 2¾ inches thick. The extremity of each chain is connected with a cast-iron saddle-piece, by bolts which pass through the vertical ribs of the saddle-piece, of which there are 15. The bottom of the saddle rests on 50 friction-rollers, which are laid on a firm horizontal bed of cast iron. The saddle can move 18 inches horizontally, either way from the centre, and thus compensate for any inequality of strain on the main chains, either from a load, or from variations of temperature.

The side main-chains are attached in like manner to the saddle, and anchored at the other extremity in an abutment of brickwork. The anchorage (Fig. 140) is arranged by passing the

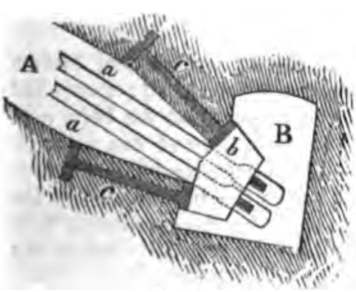


Fig. 140—Shows the manner in which the side main-chains are anchored.
A, inclined shaft for the chains leading to the arched chamber B of the anchorage.
a, *a*, two main-chains, passed through the cast-iron holding-plate *b* and fastened behind it by keys.
c, *c*, cross sections of the cast-iron girders which retain *b*.

chains through a strong cast-iron plate, and securing the ends of

he bars by keys. The anchoring-plate is retained in its place by two strong cast-iron beams, against which the strain upon the plate is thrown.

The suspending-rods (Fig. 141) are connected with both the

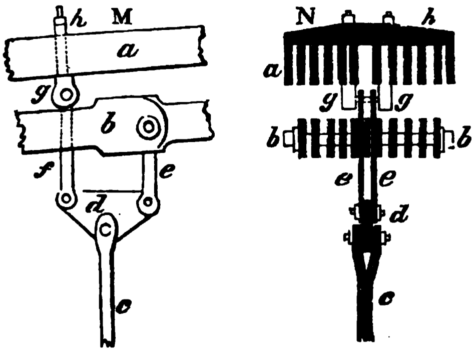


Fig. 141—Shows an elevation M and cross section N of the connection between the main-chains and suspending-rods.
a, a, upper main-chain.
b, b, joint of lower main-chain.
c, suspending-rod with a forked head to receive the plate d, hung by stirrup-straps e and f, respectively, to the coupling-bolt of the links and to the two bolts g, fastened to the saddle h on top of the upper main-chain.

upper and lower main-chains; to the upper by a saddle-piece and bolts, and to the coupling-bolt of the lower by an arrangement of articulations, which allows an easy play to the rods; at bottom (Fig. 142) they are connected by a joint with a bolt that fastens firmly the roadway-timbers.

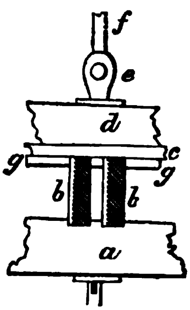


Fig. 142—Shows an elevation of the roadway-timbers.
a, bottom longitudinal beam.
b, b, roadway-bearers in pairs.
c, platform.
d, top longitudinal beam forming the bottom rail of the parapet.
e, bolt, with a forked head to receive the end of the suspending-rod, which is keyed beneath and secures the beams, &c.
g, wrought-iron horizontal diagonal ties.

The roadway-timbers consist of a strong longitudinal bottom beam, upon which the roadway-bearers are notched; these last pieces are in pairs, the two being so far apart that the bolts connecting with the suspending-rods by a forked head can pass between them; the flooring-plank is laid upon the roadway-bearers; and a top longitudinal beam, which forms the bottom rail of the parapet, is secured to the bottom beam by the connecting bolt. Wrought-iron diagonal ties are placed horizontally below the flooring, to brace the whole of the timbers beneath.

The roadway is 14 feet wide. It slopes from the centre point

along the axis to the extremities, being 4 feet higher in the centre than at the two last points.

The piers are in the form of towers, resembling the Italian belfry. They are of brick; 80 feet high, and so constructed and combined with the top saddles, that they have to sustain no other strain than the vertical pressure from the main-chains.

The whole weight of the structure, with an additional load of 100 lbs. per square foot of the roadway, would throw about 1000 tons on each pier. The tension on the chains from this load is calculated at about 1480 tons; while the strain they can bear without impairing their strength is about 5000 tons.

Monongahela wire Bridge. This bridge, erected at Pittsburgh, Penn., upon plans, and under the superintendence of Mr. Roebling, has 8 bays, varying between 188 and 190 feet in width. It is one of the more recent of these structures in the United States.

The roadway of each bay is supported by two wire cables, of $4\frac{1}{2}$ inches in diameter, and by diagonal stays of wire rope, attached to the same point of suspension as the cables, and connecting with different points of the roadway-timbers. The ends of the cables of each bay are attached to pendulum-bars, by means of two oblique arms, which are united by joints to the pendulum-bars. These bars are suspended from the top of 4 cast-iron columns, inclining inwards at top, which are there firmly united to each other; and, at bottom, anchored to the top of a stone pier built up to the level of the roadway-timbers. The side columns of each frame are connected throughout by an open lozenge-work of cast iron. The front columns have a like connection, leaving a sufficient height of passage-way for foot-passengers.

The frame-work of 4 columns on each side is firmly connected at top by cast-iron beams, in the form of an entablature. A carriage-way is left between the two frames, and a footpath between the two columns forming the fronts of each frame.

The points of suspension of the cables are over the centre line of the footpaths; and the cables are inclined so far inward that the centre point of the curve is attached just outside of the carriage-way. The suspending-ropes have a like inward inclination, the object in both cases being to add stiffness to the system, and diminish lateral oscillations.

The roadway consists of a carriage-way 22 feet wide, and two footpaths each 5 feet wide. The roadway-bearers are transversal beams in pairs, 35 feet long, 15 inches deep, and $4\frac{1}{2}$ inches wide They are attached to the suspending-ropes. The flooring consists of $2\frac{1}{4}$ inch plank, laid longitudinally over the entire roadway-surface; and of a second thickness of $2\frac{1}{4}$ inch oak plank laid transversely over the carriage-way.

The parapet, which is on the principle of Town's lattice, extends so far below the roadway-bearers that they rest and are notched on the lowest chord of the lattice. A second chord embraces them on top, and finally a third chord completes the lattice at top. The object of adopting this form of parapet was to increase the resistance of the roadway to undulations.

MOVEABLE BRIDGES

624. The term *moveable bridge* is commonly applied to a platform supported by a frame-work of timber, or of cast iron, by means of which a communication can be formed or interrupted at pleasure, between any two points of a fixed bridge, or over any narrow water-way. These bridges are generally denominated *draw-bridges*, but this term is now, for the most part, confined to those moveable bridges which can be raised or lowered by means of a horizontal axis, placed either at one extremity of the platform, or at some intermediate point between the two ends, and a counterpoise which is so connected with the platform in either case, that the bridge can be easily manœuvred by a small power acting through the intermedium of some suitable mechanism applied to the counterpoise. The term *turning* or *swinging bridge* is used when the bridge is arranged to turn horizontally around a vertical axis placed at a point between its two ends, so that the parts on each side of the axis balance each other; and the term *rolling bridge* is applied when the bridge resting upon rollers can be shoved forward or backward horizontally, to open or interrupt the passage.

To the above may be added another class of moveable bridges used for the same purpose, which consist of a platform supported by a boat, or other buoyant body, which can be placed in or withdrawn from the water-way, as circumstances may require.

625. Local circumstances will, in all cases, determine what description of moveable bridge will be best. If the width of the water-way is not over 24 feet, a single bridge may be used; but for greater widths the bridge must consist of two symmetrical parts.

626. *Draw-bridges.* When the horizontal axis of this description of bridge is placed at the extremity of the platform, the bridge is manœuvred by attaching a chain to the other extremity, which is connected with a counterpoise and a suitable mechanism, by which the slight additional power required for raising the bridge can be applied.

A number of ingenious contrivances have been put in practice for these purposes. They consist usually either of a counterpoise of invariable weight, connected with additional animal mo

tive power, which acts with constant intensity but with a variable arm of lever; or of a counterpoise of variable weight, which is assisted by animal motive power acting with an invariable arm of lever. In some cases the bridge is worked with a less complicated combination, by dispensing with a counterpoise, and applying animal motive power, of variable intensity, acting with a constant or a variable arm of lever.

Among the combinations of the first kind, the most simple consists in placing a framed lever (Fig. 143) revolving on a hori

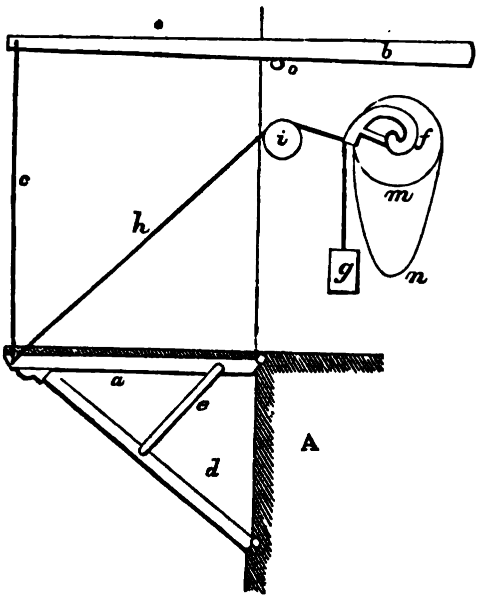


Fig. 143—Shows the manner of manœuvring a drawbridge either by a framed lever, or by a counterpoise suspended from a spiral eccentric.
A, abutment.
a, section of the platform
b, framed lever.
c, chain attached to the ends of the lever and the platform.
d, strut moveable around its lower end.
e, bar with an articulation at each end that confines the strut to the platform.
f, spiral eccentric connected with the counterpoise *g* by a chain passing over the gorge of the eccentric.
h, chain for raising the bridge, one end of which is attached to the extremity of the platform, and the other to the axle of the eccentric.
i, fixed pulley over which the chain *h* is passed.
m, Wheel fixed to the axle of the eccentric for the purpose of turning it by means of animal power applied to the endless chain *n*.

zontal axis above the platform. The anterior part of the frame is connected with the moveable extremity of the platform by two chains. The posterior portion, which forms the counterpoise. has chains attached to it by which the lever can be worked by men.

When the locality does not admit of this arrangement, the chain attached to the moveable end of the platform may be con nected with a horizontal axle above the platform, to which is also attached a fixed eccentric of a spiral shape, (Fig. 143,) connected with a chain that passes over its gorge and sustains a counterpoise of invariable weight. Upon the same axle an ordinary wheel is hung, over the gorge of which passes an endless chain to manœuvre the bridge by animal power.

Of the combinations of variable counterpoises the mechanism

of M. Poncelet, which has been successfully applied in many instances in France for the draw-bridges of military works, is one of the most simple in its arrangement and construction. The moveable end of the platform (Fig. 144) is connected by a com-

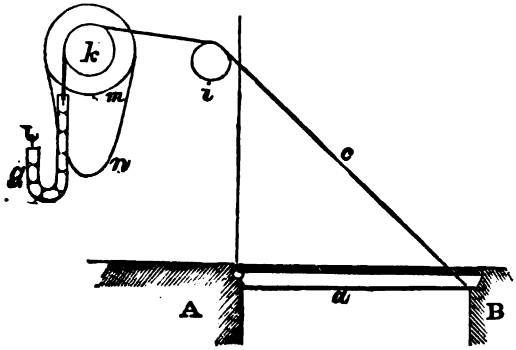


Fig. 144—Shows the arrangement of a draw-bridge with a variable counterpoise.
A and B, abutments.
g, variable counterpoise formed of a chain with flat links, one end of which is attached to a fixed point, and the other to the chain *c* attached to the moveable end of the platform.
i, fixed pulley over which the chain *c* passes to the small wheel *k* fixed on a horizontal shaft, to which is also attached the wheel *m* and the endless chain *n* for manœuvring the bridge.

mon chain, that passes over the gorge of a wheel hung upon a horizontal shaft above the platform, with another chain of variable breadth, formed of flat bar links, which forms the counterpoise. The chain counterpoise is attached at its other extremity to a fixed point in such a way, that when the platform ascends, a portion of the weight of the chain is borne by this fixed point; and thus the weight of the counterpoise decreases as the platform rises. The system is manœuvred by an endless chain passed over the gorge of a wheel hung upon the horizontal shaft.

For light platforms a counterpoise may be dispensed with, and the bridge may be manœuvred by connecting the chain attached to the moveable end of the platform to a horizontal shaft, which is turned by the usual tooth-work combinations.

When the locality does not admit of manœuvring the bridge by

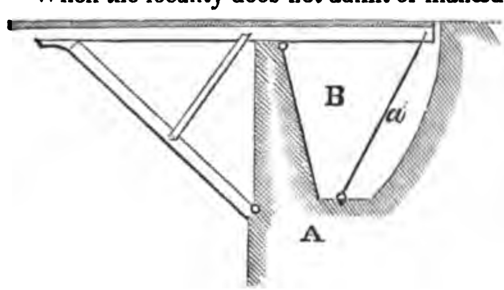


Fig. 145—Shows the arrangement of a draw-bridge where the counterpoise is formed by prolonging back the platform.
A, abutment.
B, well of a suitable form for manœuvring the bridge.
a, chain-stay to keep the platform firm when the bridge is down.

a chain connected with some point above the frame-work of the platform, Fig. 145 is continued back, from two thirds to three

fifths its length, from the face of the abutment, to form a counterpoise for the platform of the bridge. The horizontal axis of the bridge is placed near the face of the abutment, and a well of a suitable shape to receive the posterior portion of the platform that forms the counterpoise is formed behind the abutment.

The mechanism for working the bridge may consist of a chain and capstan below the platform-counterpoise, or of a suitable combination of tooth-work.

In bridges of a single platform, the moveable extremity, when the bridge is lowered, rests on the opposite abutment, and no intermediate support will be required for the structure if the frame-work be of sufficient strength; but when a double bridge, consisting of two platforms, is used, the platforms (Fig. 143) should be supported near their moveable ends, when the bridge is down, by struts moveable around the joint by which they are connected with the face of the abutments. These struts are so connected with the bridge that they are detached from it and drawn up when it is raised, and fall back into their places, abutting against blocks near the moveable end of the platform, when the bridge is down. By these arrangements the chains for working the bridge are relieved from a portion of the strain when the bridge is down, and it is also rendered more firm.

When the counterpoise is formed by the rear part of the platform, additional security may be given to the bridge when down by attaching two chains beneath the platform, and securing them to anchoring-points at the bottom of the well. In some cases a heavy bar, fitted to staples beneath connected with the timbers of the platform, is used for the same purpose.

In double bridges the two platforms when lowered should abut against each other, giving a slight elevation to the centre of the bridge. This not only gives greater stiffness, but is favorable to detaching the platforms when the bridge is to be raised.

For draw, and every kind of moveable bridge, temporary barriers should be erected on each side at the entrance upon the bridge, to prevent accidents by persons attempting to cross the bridge before it is properly secured when lowered.

627. *Turning-bridges.* These bridges revolve horizontally upon a vertical shaft, or gudgeon below the platform, which is usually thrown far enough back from the face of the abutment to place the side of the bridge, when brought round, just within this face. The weights of the parts of the bridge around the shaft should balance each other.

To support and manœuvre the bridge (Fig. 146) a circular ring of iron, or *roller-way*, of less diameter than the breadth of the bridge, and concentric with the vertical shaft, is firmly imbedded in masonry. Fixed rollers, in the shape of truncated

cones, are attached at equal distances apart to the frame-work of the platform beneath, and rest upon the roller-way. The bridge

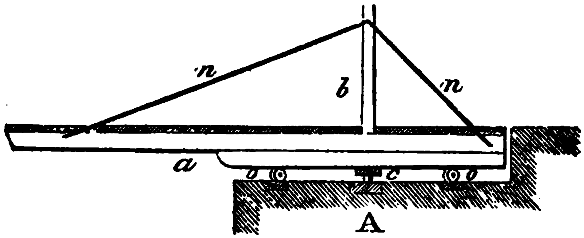


Fig. 146—Represents the arrangement of a turning-bridge.
a, platform of the bridge.
b, vertical posts to which the iron stays *n*, *n* are attached.
c, vertical shaft or gudgeon on which the bridge turns.
o, *o*, conical rollers.

is worked by a suitably arranged tooth-work, or by a chain and capstan. In some cases cast-iron balls, resting on a grooved roller-way and fitting into one of corresponding shape fixed beneath the platform, have been used for manœuvring the bridge.

The ends of the bridge are cut in the shape of circular arcs to fit recesses of a corresponding form in the abutments, so arranged as not to impede the play of the bridge.

In double turning-bridges the two ends of the platforms which come together should be of a curved shape. The platforms should be sustained from beneath by struts, like those used for draw-bridges, which can be detached and drawn into recesses when the passage is interrupted; or else they may be arranged with a ball-and-socket joint at their lower extremity, so as to be brought round with the bridge. For the purpose of giving additional strength and security to the bridge, iron stays are, in some cases, attached on each side of the platform near the extremities, and connected with vertical posts placed in a line with the vertical shaft.

Turning-bridges may be made either of timber, or of cast iron; the latter material is the more suitable, as admitting of more accuracy of workmanship, and not being liable to the derangements caused by the shrinking or warping of frame-work of timber.

628. *Rolling-bridges.* These bridges are placed upon fixed rollers, so that they can be moved forward or backward, to interrupt, or open the communication across the water-way. The part of the bridge that rests upon the rollers, when the passage is closed, must form a counterpoise to the other. The mechanism usually employed for manœuvring these bridges consists of tooth-work, and may be so arranged that it can be worked by one or more persons standing on the bridge. Instead of fixed rollers turning on axles, iron balls resting in a grooved roller-way

may be used, a similar roller-way being affixed to the frame-work beneath.

629. *Boat-bridge.* A moveable bridge of this kind may be made by placing a platform to form a roadway upon a boat, or a water-tight box of a suitable shape. This bridge is placed in, or withdrawn from the water-way, as circumstances may require, a suitable recess or mooring being arranged for it near the water way when it is left open.

A bridge of this character cannot be conveniently used in tidal waters, except at certain stages of the water. It may be employed with advantage on canals in positions where a fixed bridge could not be placed.

AQUEDUCT-BRIDGES.

630. In aqueducts and aqueduct-bridges of masonry, for supplying reservoirs for the wants of a city, or for any other purpose, the volume of water conveyed being, generally speaking, small, the structure will present no peculiar difficulties beyond affording a water-tight channel. This may be made either of masonry, or of cast-iron pipes, according to the quantity of water to be delivered. If formed of masonry, the sides and bottom of the channel should be laid in the most careful manner with hydraulic cement, and the surface in contact with the water should receive a coating of the same material, particularly if the stone or brick used be of a porous nature. This part of the structure should not be commenced until the arches have been uncentred and the heavier parts of the structure have been carried up and have had time to settle. The interior spandrel-filling, to the level of the masonry which forms the bottom of the water-way, may either be formed of solid material, of good rubble laid in hydraulic cement, or of beton well settled in layers; or a system of interior walls, like those used in common bridges for the support of the roadway, may be used in this case for the masonry of the water-way to rest on.

631. In canal aqueduct-bridges of masonry, as the volume of water required for the purposes of navigation is much greater than in the case of ordinary aqueducts, and as the structure has to be traversed by horses, every precaution should be taken to procure great solidity, and secure the work from accidents.

Segment arches of medium span will generally be found most suitable for works of this character. The section of the water-way is generally of a trapezoidal form, the bottom line being horizontal, and the two sides receiving a slight batir; its dimensions are usually restricted to allow the passage of a single boat at a time. On one side of the water-way a horse or *tow path* is

placed, and on the other a narrow footpath. The water-way should be faced with a hard cut-stone masonry, well bonded to secure it from damage from the passage of the boats. The space between the facing of the water-way, termed the *trunk* of the aqueduct, and the head-walls, is filled in with solid material, either of rubble or of beton.

A parapet-wall of the ordinary form and dimensions surmounts the tow and footpaths.

The approach to an aqueduct-bridge from a canal is made by gradually increasing the width of the trunk between the wings, which, for this purpose, usually receives a curved shape, and narrowing the water-way of the canal so as to form a convenient access to the aqueduct. Great care should be taken to form a perfectly water-tight junction between the two works.

632. When cast iron or timber is used for the trunk of an aqueduct-bridge, the abutments and piers should be built of stone. The trunk, which, if of cast iron, is formed of plates with flanches to connect them, or, if of timber, consists of one or two thicknesses of plank supported on the outside by a framing of scantling, may be supported by a bridge-frame of cast iron, or of timber, or be suspended from chains or wire cables.

The tow-path may be placed either within the water-way, or, as is most usually done, without. It generally consists of a simple flooring of plank laid on cross-joists supported from beneath by suitably arranged frame-work.

633. The following succinct descriptions of some of the aqueduct-bridges of the United States and of Europe are derived from authentic sources.

Chirk Aqueduct-bridge over the *Ceriog*. This work, built by Telford, consists of 10 full centre arches of masonry, of 40 feet span each. The water-way is only 11 feet wide and 5 feet deep. The tow-path 6 feet wide.

The piers of this work, which in some places are over 100 feet in height, are built hollow for some distance below the top; the facing being connected by cross-walls upon which the bottom of the water-way, formed of broad iron-flanched plates, and the masonry of the sides rest.

Pont-y-Cystile Aqueduct-bridge over the *Dee*. This is also one of Telford's early works. The trunk is of cast-iron plates connected by flanches. These rest upon stone piers and upon a bridge-frame of cast iron consisting of four ribs of solid panels. The span of the ribs is 45 feet and the rise $7\frac{1}{2}$ feet.

The breadth of the water-way is 11 feet 10 inches. The tow-path is 4 feet 8 inches wide, and is placed within the water way, resting upon cast-iron uprights.

The canal aqueduct-bridges at *Guétin* over the *Allier*, and a

Digoin upon the *Loire*, are among the more recent structures of this character in France. They are both built upon the same plan, and of mixed masonry. The first has eighteen arches; the second eleven. The span of each arch is 52½ feet, and the rise about 23 feet. The piers are about 10 feet thick at the im post. The breadth of the aqueduct between the heads is 31 feet, and that of the water-way about 16 feet.

Rochester Canal Aqueduct-bridge. This is the most recent and the largest aqueduct-bridge built entirely of masonry in the United States. It consists of seven segment arches. Its water way is of sufficient width for the passage of two boats, and is adapted to the enlargement of the Erie canal. The span of each arch is 52 feet; the rise 10 feet. The key-stone is 2 feet 6 inches in depth, and the top of it is on a level with the bottom of the trunk. The piers are 10 feet thick at the impost. The water-way is 9 feet in depth, the masonry of the sides receiving a batir of 2 inches in one foot. The depth of water is 7 feet, and the width at the water-line 45 feet. The sides of the water-way, the top surface of which forms the tow-paths, are 11 feet in width at top, including the projection of the coping. The trunk at each extremity is gradually enlarged, in a curved shape, to the width of 55 feet, where it unites with the slopes of the water-way of the canal.

This work is built throughout in a very strong and superior manner, of heavy blocks of gray lime-stone laid in hydraulic mortar.

Potomac Canal Aqueduct-bridge. This work, originally intended to be of stone throughout, was to have consisted of twelve oval arches of eleven centres, the span of each being 100 feet, and the rise 25 feet. Every third pier forms an abutment-pier, and is 21 feet thick at the impost; the others are only 12 feet thick at the same level. The piers have been built upon the original design, but a wooden superstructure, consisting of the trunk of the aqueduct, a tow-path, and the frame-work for their support, has been substituted for the stone arches.

The trunk (Fig. 147) is formed of a frame consisting of two parallel open-built beams, connected at bottom by parallel cross-joists and horizontal diagonal braces, which are sheathed on the interior with plank to form the water-way.

Each of the open-built beams is composed of a top and bottom string connected by uprights that project above and below the strings, and by single diagonal braces placed between each pair of uprights.

The tow-path is placed on the outside of the trunk, and consists of a flooring laid upon cross-joists placed between one of the built beams of the trunk and a third parallel to it.

The exterior-built beam of the tow-path is framed of smaller scantling than the other two. It is connected with the built

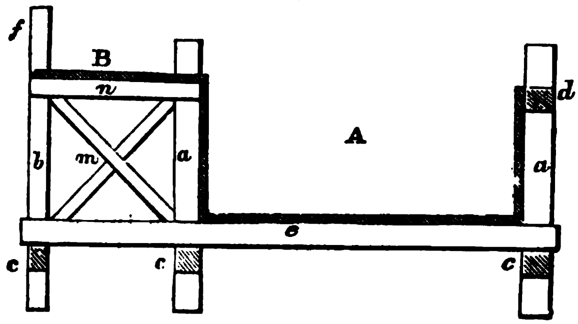


Fig. 147—Represents a cross section of the trunk and tow-path of the Potomac canal aqueduct-bridge.
A, interior of trunk.
B, tow-path.
a, a, uprights of the open-built beams on the sides of the trunk.
b, upright of the open-built beam of the tow-path.
c, lower strings of the built beams.
d, upper string.
e, cross-joists on which the sheathing of the bottom of the trunk rests.
n, cross-joists of the tow-path.
m, vertical diagonal braces between the cross joists.
f, parapet.

beam of the trunk by every fourth cross-joist of the trunk, by the top cross-joists of the flooring, and by vertical diagonal braces placed between each pair of top and bottom cross-joists.

The uprights of the exterior-built beam of the tow-path project sufficiently high above the flooring to form a parapet.

The frame-work of the trunk and tow-path is supported at intermediate points from beneath by inclined struts which abut against the faces of the piers at a point above the high-water level.

The section of the water-way is rectangular. The interior width is 17 feet; the height of the sheathing 8 feet 4 inches within; and the depth of water 4 feet 4 inches.

The surface of the tow-path is 6 feet wide between the uprights of the built beams, and is on a level with the top of the sheathing. The exterior parapet is 3 feet 10 inches above the level of the tow-path, and an interior parapet, 2 feet above the same level, is formed by a capping on the uprights of the built beam, making the height of the capping on each side of the trunk 10 feet 4 inches above the sheathing of the bottom.

The frame-work of this structure is simple in its combinations and well arranged both for strength and stiffness.

Wire Suspension Canal Aqueduct-bridge over the *Alleghany* river at *Pittsburgh*. This novel work (Fig. 148) was planned

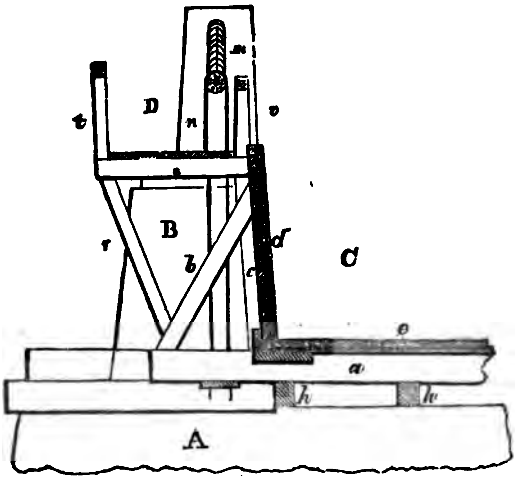


Fig. 148—shows in elevation a portion of the stone supports, and a cross section of the trunk, &c., of the Alleghany canal aqueduct-bridge.
A, piers.
B, Supports of masonry on the piers for the wire cables.
C, interior of a portion of the trunk.
a, cross-joists suspended from the cables *m* by the bent suspending-bars *n*, on which the bottom *e* of trunk rests.
b, inclined struts in pairs connected with the pieces *c* to support the sides *d* of the trunk.
D, tow-path.
s, cross-joists of the tow-path.
r, inclined supports of *s*.
t and *v*, parapets.
h, sleepers on top of the piers on which the cross-joists *a* rest.

and constructed by Mr. Roebling, through whom the following detailed description was obtained:

"This work is formed of seven spans of 160 feet each from centre to centre of pier. The trunk is of wood and 1140 feet long, 14 feet wide at bottom, 16½ feet wide on top; the sides 8½ feet deep. These as well as the bottom are composed of a double course of 2½ inch white-pine plank laid diagonally, the two courses crossing each other at right angles, so as to form a solid lattice-work of great strength and stiffness, sufficient to bear its own weight and resist the effects of the most violent storms. The bottom of the trunk rests upon transverse beams, arranged in pairs 4 feet apart; between these the posts which support the sides of the trunk are let in with dove-tailed tenons, secured by bolts. The outside posts which support the side-walk and tow-path incline outwards and are connected with the beams in a similar manner. Each trunk-post is held by two braces 2½×10 inches, and connected with the outside posts by a double joist of 2½×10. The trunk-posts are 7 inches square at the top and

7×14 at the heel. The transverse beams are 27 feet long 16 inches deep, and 6 inches wide; the space between the two adjoining is 4 inches. It will be observed that all parts of the frame, with the exception of the posts, are double, so as to admit the suspension-rods. Each pair of beams is supported on each side of the trunk by *double* suspending-rods of 1¼ inch round bar-iron, bent in the shape of a stirrup, and mounted on a small cast-iron saddle, which rests on the cable. These saddles are on top of the cables connected by links, which diminish in size from the pier towards the centre. The sides of the trunk rest solid against the bodies of masonry, which are erected on each pier and abutment as *bases* for the pyramids which support the cables. These pyramids, which are constructed of three blocks or courses of a durable coarse-grained hard mountain sand-stone, rise 5 feet above the level of the side-walk and tow-path, and measure 3×5 feet on top, and 4×6½ feet in base. The side-walk and tow-path being 7 feet wide, leave 3 feet space outside for the passage of the pyramids; the ample width of the tow and footpath is therefore contracted on every pier; but this arrangement proves no inconvenience, and was necessary for the suspension of the cables next to the trunk.

"As the caps which cover the saddles and cables on the pyramids rise 3 feet above the inside, or trunk-railing, they would obstruct the passage of the tow-line; this however is obviated by a slide-rod of round iron, which passes over the top of the cap and forms a gradual slope down to the railing on each side of the pyramid.

"The wire cables, which are the main support of the structure, are suspended next to the trunk, one on each side. Each of these two cables is exactly 7 inches in diameter, perfectly solid and compact, and constructed in one piece from shore to shore, 1175 feet long; it is composed of 1900 wires of ⅛ inch diameter, which are laid parallel to each other. Great care has been taken to insure an equal tension of the wires. The oxidation of the wires is guarded against by a varnish applied to each separately. The preservation of the cables is insured by a close, compact, and continuous wrapping, made of annealed wire and laid on by machinery in the most perfect manner

"The extremities of the cables on the aqueduct do not extend *below* ground, but connect with anchor-chains, which in a curved line pass through large masses of masonry, the last links occupying a vertical position. The bars composing these chains average 1¼×4 inches, and are from 4 to 12 feet long; they are manufactured of boiler-scrap, and forged in one piece without a weld. The extreme links are anchored to heavy cast-iron plates of 6 feet square, which are held down by the foundations, upon

which the weight of 700 perches of masonry rests. The stability of this part of the structure is fully insured, as the resistance of the anchorage is twice as great as the greatest strain to which the chains can ever be subjected.

"The plan of anchorage adopted on the aqueduct varies materially from those methods usually applied to suspension bridges, where an open channel is formed under ground for the passage of the chains. The chains below ground are imbedded and completely surrounded by cement. In the construction of the masonry this material and common lime-mortar have been abundantly applied. The bars are painted with red lead: their preservation is rendered certain by the known quality of calcareous cements to prevent oxidation. If moisture should find its way to the chains, it will be saturated with lime, and add another calcareous coating to the iron. This portion of the work has been executed with scrupulous care, so as to render it unnecessary, on the part of those who exercise a surveillance over the structure, to examine it. The repainting of the cables every two or three years will insure their duration for a long period.

"Where the cables rest on the saddles, their size is increased at two points, by introducing short wires and forming swells which fit into corresponding recesses of the casting. Between these swells the cable is forcibly held down by three sets of strong iron wedges, driven through openings which are cast in the sides of the saddle. During the raising of the frame-work, the several arches were frequently subjected to very unequal and considerable forces, which never disturbed the balance, and proved the correctness of previous calculations. The woodwork in any of the arches, separately, may be removed and substituted by new material, without affecting the equilibrium of the next one.

"The original idea upon which the plan has been perfected, was to form a *wooden trunk*, strong enough to support its own weight, and stiff enough for an aqueduct, or bridge, and to combine this structure with wire cables, of a sufficient strength to bear safely the great weight of water.

"*Table of Quantities on Aqueduct.*

Length of aqueduct without extensions	1140 feet.
Length of cables	1175 "
Length of cables and chains	1283 "
Diameter of cables	7 inches.
Aggregate weight of both cables	110 tons.
Section of 4 feet of water in trunk	59 superf. feet
Total weight of water in aqueduct	2100 tons.
Do. do. in one span	295 "
Weight of one span including all	420 "
Aggregate number of wires in both cables .	3800

Aggregate solid section of both cables* . . .	53 superf. inch
Do. do. anchor-chains . .	72 "
Deflection of cables	14 feet 6 inch
Elevation from top of pyramids to top of piers . .	16 " 6 "
Weight of water in one span between piers . .	275 tons.
Tension of cables resulting from this weight . .	392 "
Tension of one single wire	206 lbs.
Average ultimate strength of one wire . . .	1100 "
Ultimate strength of cables	2090 tons.
Tension resulting from weight of water upon 1 solid square inch of wire cable	14800 lbs.
Tension resulting from weight of water upon 1 square inch of anchor-chains	11000 "
Pressure resulting from water upon a pyramid . .	137½ tons
Do. upon one superficial foot . .	18400 lbs."

See Note A. Appendix.

ROADS.

634. In establishing a line of internal communication of any character, whether it be an ordinary road, railroad, or canal, the main considerations to which the attention of the engineer must be directed in the outset are—1, the probable character and amount of traffic over the line; 2, the wants of the community in the neighborhood of the line; 3, the natural features of the country, between the points of *arrival* and *departure*, as regards their adaptation to the proposed communication.

As the last point alone comes exclusively within the province of the engineer's art, and within the limits prescribed to this work, attention will be confined solely to its consideration.

635. *Reconnaissance.* A thorough examination and study of the ground by the eye, termed a *reconnaissance*, is an indispensable preliminary to any more accurate and minute survey by instruments, to avoid loss of time, as by this more rapid operation any ground unsuitable for the proposed line will be as certainly detected by a person of some experience, as it could be by the slow process of an instrumental survey. Before however proceeding to make a reconnaissance, a careful inspection of the general maps of that portion of the country through which the communication is to pass, will facilitate, and may considerably abridge, the labors of the engineer; as from the natural features laid down upon them, particularly the direction of the water-courses, he will at once be able to detect those points which will be favorable, or otherwise, to the general direction selected for the line. This will be sufficiently evident when it is considered —1, that the water-courses are necessarily the lowest lines of the valleys through which they flow, and that their direction must also be that of the lines of greatest declivity of their respective valleys; 2, that from the position of the water-courses the position also of the high grounds by which they are separated naturally follows, as well as the approximate position at least of the ridges, or highest lines of the high grounds, which separate their opposite slopes, and which are at the same time the lines of greatest declivity common to these slopes, as the water-courses are the corresponding lines of the slopes that form the valleys.

Keeping these facts (which are susceptible of rigid mathematical demonstration) in view, it will be practicable, from a careful examination of an ordinary general map, if accurately constructed, not only to trace, with considerable accuracy, the general direc

tion of the ridges from having that of the water-courses, but also to detect those depressions in them which will be favorable to the passage of a communication intended to connect two main or two secondary valleys. The following illustrations may serve to place this subject in a clearer aspect.

If, for example, it be found that on any portion of a map the water-courses seem to diverge from or converge towards one point, it will be evident that the ground in the first case must be the common source or supply of the water-courses, and therefore the highest; and in the second case that it is the lowest, and forms their common recipient.

If two water-courses flow in opposite directions from a common point, it will show that this is the point from which they derive their common supply, at the head of their respective valleys, and that it must be fed by the slopes of high grounds above this point; or, in other words, that the valleys of the two water-courses are separated by a chain of high grounds, which, at the point where it crosses them, presents a depression in its ridge, which would be the natural position for a communication connecting the two valleys.

If two water-courses flow in the same direction and parallel to each other, it will simply indicate a general inclination of the ridge between them, in the same direction as that of the water-courses. The ridge, however, may present in its course elevations and depressions, which will be indicated by the points in which the water-courses of the secondary valleys, on each side of it, intersect each other on it; and these will be the lowest points at which lines of communication, through the secondary valleys, connecting the main water-courses, would cross the dividing ridge.

If two water-courses flow in the same direction, and parallel to each other, and then at a certain point assume divergent directions, it will indicate that this is the lowest point of the ridge betweeen them.

If two water-courses flow in parallel but opposite directions, depressions in the ridge between them will be shown by the meeting of the water-courses of the secondary valleys on the ridge; or by an approach towards each other, a any point, of the two principal water-courses.

Furnished with the data obtained from the maps, the character of the ground should be carefully studied both ways by the engineer, first from the point of departure to that of arrival, and then returning from the latter to the former, as without this double traverse natural features of essential importance might escape the eye.

636. *Surveys*. From the results of the reconnaissance, the

engineer will be able to direct understandingly the requisite surveys, which consist in measuring the lengths, determining the directions, and ascertaining both the longitudinal and cross levels of the different routes, or, as they are termed, *trial lines*, with sufficient accuracy to enable him to make a comparative estimate both of their practicability and cost. As the expense of making the requisite surveys is usually but a small item compared with that of constructing the communication, no labor should be spared in running every practicable line, as otherwise natural features might be overlooked which might have an important influence on the cost of construction.

637. *Map and Memoir.* The results of the surveys are accurately embodied in a map exhibiting minutely the topographical features and sections of the different trial lines, and in a memoir which should contain a particular description of those features of the ground that cannot be shown on a map, with all such information on other points that may be regarded as favorable, or otherwise, to the proposed communication; as, for example, the nature of the soil, that of the water-courses met with, &c., &c.

638. *Location of common Roads.* In selecting among the different trial-lines of the survey the one most suitable to a common road, the engineer is less restricted, from the nature of the conveyance used, than in any other kind of communication. The main points to which his attention should be confined are—1, to connect the points of arrival and departure by the most direct, or shortest line; 2, to avoid unnecessary ascents and descents, or, in other words, to reduce the ascents and descents to the smallest practicable limit; 3, to adopt such suitable slopes, or *gradients*, for the *axis*, or centre line of the road, as the nature of the conveyance may demand; 4, to give the axis such a position, with regard to the surface of the ground and the natural obstacles to be overcome, that the cost of construction for the excavations and embankments required by the gradients, and for the bridges and other accessories, shall be reduced to the lowest amount.

639. Deviations from the right line drawn on the map, between the points of arrival and departure, will be often demanded by the natural features of the ground. In passing the dividing ridges of main, or secondary valleys, for example, it will frequently be found more advantageous, both for the most suitable gradients, and to diminish the amount of excavation and embankment, to cross the ridge at a lower point than the one in which it is intersected by the right line, deviating from the right line either towards the *head*, or upper part of the valley, or towards its outlet, according to the advantages presented by the natural features of the ground, both for reducing the gradients and the amount of excavation and embankment

Where the right line intersects either a marsh, or water-course, it may be found less expensive to change the direction, avoiding the marsh, or intersecting the water-course at a point where the cost of construction of a bridge, or of the approaches to it, wil be more favorable than the one in which it is intersected by the right line.

Changes from the direction of the right line may also be favorable for the purpose of avoiding the intersection of secondary water-courses; of gaining a better soil for the roadway; of giving a better exposure of its surface to the sun and wind; or of procuring better materials for the road-covering.

By a careful comparison of the advantages presented by these different features, the engineer will be enabled to decide how far the general direction of the right line may be departed from with advantage to the location. By choosing a more sinuous course the length of the line will often not be increased to any very considerable degree, while the cost of construction may be greatly reduced, either in obtaining more favorable gradients, or in lessening the amount of excavation and embankment.

640. When the points of arrival and departure are upon different levels, as is usually the case, it will seldom be practicable to connect them by a continual ascent. The most that can be done will be to cross the dividing ridges at their lowest points, and to avoid, as far as practicable, the intersection of considerable secondary valleys which might require any considerable ascent on one side and descent on the other.

641. The gradients upon common roads will depend upon the kind of material used for the road-covering, and upon the state in which the road-surface is kept. The gradient in all cases should be less than the *angle of repose*, or of that inclination of the axis of the road in which the ordinary vehicles for transportation would remain at a state of rest, or, if placed in motion, would descend by the action of gravity with uniform velocity.

The gradients corresponding to the angle of repose have been ascertained by experiments made upon the various road-coverings in ordinary use, by allowing a vehicle to descend along a road of variable inclination until it was brought to a state of rest by the retarding force of friction; also, by ascertaining the amount of force, termed *the force of traction*, requisite to put in motion a vehicle with a given load on a level road.

The following are the results of experiments made by Mr Macneill, in England, to determine the force of traction for one ton upon level roads.

No. 1.	Good pavement, the force of traction is .	33 lbs
" 2.	Broken stone surface laid on an old flint road	65 "
" 3.	Gravel road	147 "

No. 4. Broken-stone surface on a rough pavement bottom . . . . 16 lbs.
" 5. Broken-stone surface on a bottom of beton . 46 "

From this it appears that the angle of repose in the first case is represented by $\frac{33}{2240}$, or $\frac{1}{68}$ nearly; and that the slope of the road should therefore not be greater than one perpendicular to sixty-eight in length; or that the height to be overcome must not be greater than one sixty-eighth of the distance between the two points measured along the road, in order that the force of friction may counteract that of gravity in the direction of the road.

A similar calculation will show that the angle of repose in the other cases will be as follows:

No. 2, ...	1 to . . .	35 nearly.
" 3, ...	1 to . . .	15 "
" 4 and 5, . . .	1 to . . .	49 "

These numbers, which give the angle of repose between $\frac{1}{35}$ and $\frac{1}{45}$ for the kinds of road-covering Nos. 2 and 4 in most ordinary use, and corresponding to a road-surface in good order may be somewhat increased, to from $\frac{1}{28}$ to $\frac{1}{33}$, for the ordinary state of the surface of a well-kept road, without there being any necessity for applying a brake to the wheels in descending, or going out of a trot in ascending. The steepest gradient that can be allowed on roads with a broken-stone covering is about $\frac{1}{20}$, as this, from experience, is found to be about the angle of repose upon roads of this character in the state in which they are usually kept. Upon a road with this inclination, a horse can draw at a walk his usual load for a level without requiring the assistance of an extra horse; and experience has farther shown that a horse at the usual walking pace will attain, with less apparent fatigue, the summit of a gradient of $\frac{1}{20}$ in nearly the same time that he would require to reach the same point on a trot over a gradient of $\frac{1}{33}$.

A road on a dead level, or one with a continued and uniform ascent between the points of arrival and departure, where they lie upon different levels, is not the most favorable to the draft of the horse. Each of these seems to fatigue him more than a line of alternate ascents and descents of slight gradients; as, for example, gradients of $\frac{1}{100}$, upon which a horse will draw as heavy a load with the same speed as upon a horizontal road.

The gradients should in all cases be reduced as far as practicable, as the extra exertion that a horse must put forth in overcoming heavy gradients is very considerable; they should as a general rule, therefore, be kept as low at least as $\frac{1}{33}$, wherever the ground will admit of it. This can generally be effected, even in ascending steep hill-sides, by giving the axis of the road a zig-

zag direction, connecting the straight portions of the zigzags by circular arcs. The gradients of the curved portions of the zigzags should be reduced, and the roadway also at these points be widened, for the safety of vehicles descending rapidly. The width of the roadway may be increased about one fourth, when the angle between the straight portions of the zigzags is from 120° to 90°; and the increase should be nearly one half where the angle is from 90° to 60°.

642. Having laid down upon the map the approximate location of the axis of the road, a comparison can then be made between the solid contents of the excavations and embankments, which should be so adjusted that they shall balance each other, or, in other words, the necessary excavations shall furnish sufficient earth to form the embankments. To effect this, it will frequently be necessary to alter the first location, by shifting the position of the axis to the right or left of the position first assumed, and also by changing the gradients within the prescribed limits. This is a problem of very considerable intricacy, whose solution can only be arrived at by successive approximations. For this purpose, the line must be subdivided into several portions, in each of which the equalization should be attempted independently of the rest, instead of trying a general equalization for the whole line at once.

In the calculations of solid contents required in balancing the excavations and embankments, the most accurate method consists in subdividing the different solids into others of the most simple geometrical forms, as prisms, prismoids, wedges, and pyramids, whose solidities are readily determined by the ordinary rules for the mensuration of solids. As this process, however, is frequently long and tedious, other methods requiring less time but not so accurate, are generally preferred, as their results give an approximation sufficiently near the true for most practical purposes. They consist in taking a number of equidistant profiles, and calculating the solid contents between each pair, either by multiplying the half sum of their areas by the distance between them, or else by taking the profile at the middle point between each pair, and multiplying its area by the same length as before. The latter method is the more expeditious; it gives less than the true solid contents, but a nearer approximation than the former, which gives more than the true solid contents, whatever may be the form of the ground between each pair of cross profiles.

In calculating the solid contents, allowance must be made for the difference in bulk between the different kinds of earth when occupying their natural bed and when made into embankment From some careful experiments on this point made by Mr. Elwood Morris, a civil engineer, and published in the Franklin Journal

it appears that light sandy earth occupies the same space both in excavation and embankment; clayey earth about one tenth less in embankment than in its natural bed; gravelly earth also about one twelfth less; rock in large fragments about five twelfths more, and in small fragments about six tenths more.

643. Another problem connected with the one in question, is that of determining the *lead*, or the mean distance to which the earth taken from the excavations must be carried to form the embankments. From the manner in which the earth is usually transported from the one to the other, this distance is usually that between the centre of gravity of the solid of excavation and that of its corresponding embankment. Whatever disposition may be made of the solids of excavation, it is important, so far as the cost of their removal is concerned, that the lead should be the least possible. The solution of the problem under this point of view will frequently be extremely intricate, and demand the application of all the resources of the higher analysis. One general principle however is to be observed in all cases, in order to obtain an approximate solution, which is, that in the removal of the different portions of the solid of excavation to their corresponding positions on that of the embankment, the paths passed over by their respective centres of gravity shall not cross each other either in a horizontal, or vertical direction. This may in most cases be effected by intersecting the solids of excavation and embankment by vertical planes in the direction of the removal, and by removing the partial solids between the planes within the boundaries marked out by them.

644. The definitive location having been settled by again going over the line, and comparing the features of the ground with the results furnished by the preceding operations, general and detailed maps of the different divisions of the definitive location are prepared, which should give, with the utmost accuracy, the longitudinal and cross sections of the natural ground, and of the excavations and embankments, with the horizontal and vertical measurements carefully written upon them, so that the superintending engineer may have no difficulty in setting out the work from them on the ground.

In addition to these maps, which are mainly intended to guide the engineer in regulating the earth-work, detailed drawings of the road-covering, of the masonry and carpentry of the bridges, culverts, &c., accompanied by written specifications of the manner in which the various kind of work is to be performed, should be prepared for the guidance both of the engineer and workmen.

645. With the data furnished by the maps and drawings, the engineer can proceed to set out the line on the ground. The axis of the road is determined by placing stout stakes, or pickets,

at equal intervals apart, which are numbered to correspond with the same points on the map. The width of the roadway and the lines on the ground corresponding to the side slopes of the excavations and embankments, are laid out in the same manner, by stakes placed along the lines of the cross profiles.

Besides the numbers marked on the stakes, to indicate their position on the map, other numbers, showing the depth of the excavations, or the height of the embankments from the surface of the ground, accompanied by the letters *Cut. Fill.* to indicate a *cutting*, or a *filling*, as the case may be, are also added to guide the workmen in their operations. The positions of the stakes on the ground, which show the principal points of the axis of the road, should, moreover, be laid down on the map with great accuracy, by ascertaining their bearings and distances from any fixed and marked objects in their vicinity, in order that the points may be readily found should the stakes be subsequently misplaced.

646. *Earth-work.* This term is applied to whatever relates to the construction of the excavations and embankments, to prepare them for receiving the road-covering.

647. In forming the excavations, the inclination of the side slopes demands peculiar attention. This inclination will depend on the nature of the soil, and the action of the atmosphere and internal moisture upon it. In common soils, as ordinary garden earth formed of a mixture of clay and sand, compact clay, and compact stony soils, although the side slopes would withstand very well the effects of the weather with a greater inclination, it is best to give them two base to one perpendicular; as the surface of the roadway will, by this arrangement, be well exposed to the action of the sun and air, which will cause a rapid evaporation of the moisture on the surface. Pure sand and gravel may require a greater slope, according to circumstances. In all cases where the depth of the excavation is great, the base of the slope should be increased. It is not usual to use any artificial means to protect the surface of the side slopes from the action of the weather; but it is a precaution which, in the end, will save much labor and expense in keeping the roadway in good order. The simplest means which can be used for this purpose, consist in covering the slopes with good sods, (Fig. 149,) or else with a layer



Fig. 149—Cross section of a road in excavation.
A, road-surface.
B, side slopes.
C, top surface-drain.

of vegetable mould about four inches thick, carefully laid and sown with grass seed. These means will be amply sufficient to protect the side slopes from injury when they are not exposed to

any other causes of deterioration than the wash of the rain, and the action of frost on the ordinary moisture retained by the soil.

The side slopes form usually an unbroken surface from the foot to the top. But in deep excavations, and particularly in soils liable to slips, they are sometimes formed with horizontal offsets, termed *benches*, which are made a few feet wide and have a ditch on the inner side to receive the surface-water from the portion of the side slope above them. These benches catch and retain the earth that may fall from the portion of the side slope above.

When the side slopes are not protected, it will be well, in localities where stone is plenty, to raise a small wall of dry stone at the foot of the slopes, to prevent the wash of the slopes from being carried into the roadway.

A covering of brush wood, or a thatch of straw, may also be used with good effect; but, from their perishable nature, they will require frequent renewal and repairs.

In excavations through solid rock, which does not disintegrate on exposure to the atmosphere, the side slopes might be made perpendicular; but as this would exclude, in a great degree, the action of the sun and air, which is essential to keeping the road-surface dry and in good order, it will be necessary to make the side slopes with an inclination, varying from one base to one perpendicular, to one base to two perpendicular, or even greater, according to the locality; the inclination of the slope on the south side in northern latitudes being greatest, to expose better the road-surface to the sun's rays.

The slaty rocks generally decompose rapidly on the surface, when exposed to moisture and the action of frost. The side slopes in rocks of this character may be cut into steps, (Fig. 150,)



and then be covered by a layer of vegetable mould sown in grass seed, or else the earth may be sodded in the usual way.

648. The stratified soils and rocks, in which the strata have a *dip*, or inclination to the horizon, are liable to *slips*, or to give way by one stratum becoming detached and sliding on another which is caused either from the action of frost, or from the pressure of water, which insinuates itself between the strata. The worst soils of this character are those formed of alternate strata of clay and sand; particularly if the clay is of a nature to become semi-fluid when mixed with water. The best preventives that can be

resorted to in these cases, are to adopt a thorough system of drainage, to prevent the surface-water of the ground from running down the side slopes, and to cut off all springs which run towards the roadway from the side slopes. The surface-water may be cut off by means of a single ditch (Fig. 149) made on the up-hill side of the road, to catch the water before it reaches the slope of the excavation, and convey it off to the natural water-courses most convenient; as, in almost every case, it will be found that the side slope on the down-hill side is, comparatively speaking, but slightly affected by the surface-water.

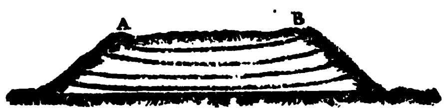
Where slips occur from the action of springs, it frequently becomes a very difficult task to secure the side slopes. If the sources can be easily reached by excavating into the side slopes, drains formed of layers of fascines, or brush-wood, may be placed to give an outlet to the water, and prevent its action upon the side slopes. The fascines may be covered on top with good sods laid with the grass side beneath, and the excavation made to place the drain be filled in with good earth well rammed. Drains formed of broken stone, covered in like manner on top with a layer of sod to prevent the drain from becoming choked with earth, may be used under the same circumstances as fascine drains. Where the sources are not isolated, and the whole mass of the soil forming the side slopes appears saturated, the drainage may be effected by excavating trenches a few feet wide at intervals to the depth of some feet into the side slopes, and filling them with broken stone, or else a general drain of broken stone may be made throughout the whole extent of the side slope by excavating into it. When this is deemed necessary, it will be well to arrange the drain like an inclined retaining-wall, with buttresses at intervals projecting into the earth farther than the general mass of the drain. The front face of the drain should, in this case, also be covered with a layer of sods with the grass side beneath, and upon this a layer of good earth should be compactly laid to form the face of the side slopes. The drain need only be carried high enough above the foot of the side slope to tap all the sources; and it should be sunk sufficiently below the roadway-surface to give it a secure footing.

The drainage has been effected, in some cases, by sinking wells or *shafts* at some distance behind the side slopes, from the top surface to the level of the bottom of the excavation, and leading the water which collects in them by pipes into drains at the foot of the side slopes. In others a narrow trench has been excavated, parallel to the axis of the road, from the top surface to a sufficient depth to tap all the sources which flow towards the side slope, and a drain formed either by filling the trench wholly with broken stone, or else by arranging an open conduit at the

bottom to receive the water collected, over which a layer of brushwood is laid, the remainder of the trench being filled with broken stone.

In some recent instances in England, the side slopes of very bad soils have been secured by a facing of brick arranged in a manner very similar to the method resorted to for securing the perpendicular sides of narrow deep trenches by a timber-facing. The plan pursued is to place, at intervals along the excavation, strong buttresses of brick on each side, opposite to each other, and to connect them at bottom by a reversed arch. Between these buttresses are placed, at suitable heights, one or more brick beams, formed at bottom with a flat segment arch, and at top with a like inverted arch. The buttresses, secured in this way, serve as piers for vertical cylindrical arches, which form the facing and support the pressure of the earth between the buttresses.

649. In forming the embankments, (Fig. 151,) the side slopes

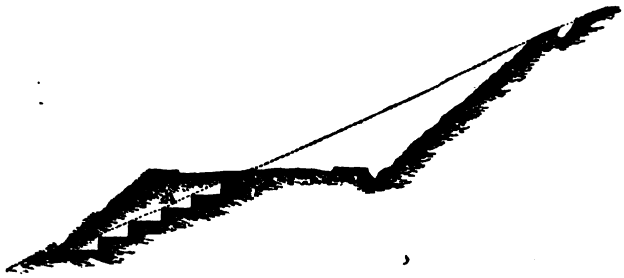


should be made with a less inclination than that which the earth naturally assumes; for the purpose of giving them greater durability, and to prevent the width of the top surface, along which the roadway is made, from diminishing by every change in the side-slopes, as it would were they made with the natural slope To protect the side slopes more effectually, they should be sodded, or sown in grass seed; and the surface-water of the top should not be allowed to run down them, as it would soon wash them into gullies, and destroy the embankment. In localities where stone is plenty, a sustaining wall of dry stone may be advantageously substituted for the side slopes.

To prevent, as far as possible, the settling which takes place in embankments, they should be formed with great care; the earth being laid in successive layers of about four feet in thickness, and each layer well settled with rammers. As this method is very expensive, it is seldom resorted to except in works which require great care, and are of trifling extent. For extensive works, the method usually followed on account of economy, is to embank out from one end, carrying forward the work on a level with the top surface. In this case, as there must be a want of compactness in the mass, it would be best to form the outsides of the embankment first, and to gradually fill in towards the centre, in order that the earth may arrange itself in layers with a dip from the sides inwards: this will in a great measure counteract

any tendency to slips outward. The foot of the slopes should be secured by buttressing them either by a low stone wall, or by forming a slight excavation for the same purpose.

650. When the axis of the roadway is laid out on the side slope of a hill, and the road-surface is formed partly by excavating and partly by embanking out, the usual and most simple method is to extend out the embankment gradually along the whole line of excavation. This method is insecure, and no pains therefore should be spared to give the embankment a good footing on the natural surface upon which it rests, particularly at the foot of the slope. For this purpose the natural surface (Fig. 152)



should be cut into steps, or offsets, and the foot of the slope be secured by buttressing it against a low stone wall, or a small terrace of carefully rammed earth.

In side-formings along a natural surface of great inclination, the method of construction just explained will not be sufficiently secure; sustaining-walls must be substituted for the side slopes, both of the excavations and embankments. These walls may be made simply of dry stone, when the stone can be procured in blocks of sufficient size to render this kind of construction of sufficient stability to resist the pressure of the earth. But when the blocks of stone do not offer this security, they must

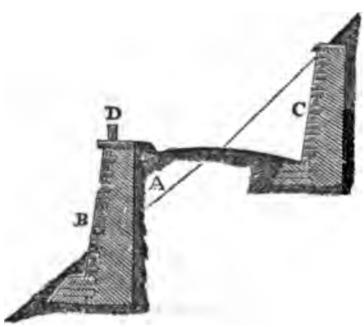


Fig. 153—Cross section of a road in steep side-forming.
A, filling.
B, sustaining-wall of filling.
C, breast-wall of cutting.
D, parapet-wall of footpath.

be laid in mortar, (Fig. 153,) and hydraulic mortar is the only

kind which will form a safe construction. The wall which supplies the slope of the excavation should be carried up as high as the natural surface of the ground; the one that sustains the embankment should be built up to the surface of the roadway; and a parapet-wall should be raised upon it, to secure vehicles from accidents in deviating from the line of the roadway.

A road may be constructed partly in excavation and partly in embankment along a rocky ledge, by blasting the rock, when the inclination of the natural surface is not greater than one perpendicular to two base; but with a greater inclination than this, the whole should be in excavation.

651. There are examples of road constructions, in localities like the last, supported on a frame-work, consisting of horizontal pieces, which are firmly fixed at one end by being let into holes drilled in the rock, and are sustained at the other by an inclined strut underneath, which rests against the rock in a shoulder formed to receive it.

652. When the excavations do not furnish sufficient earth for the embankments, it is obtained from excavations, termed *side-cuttings*, made some place in the vicinity of the embankment, from which the earth can be obtained with the most economy.

If the excavations furnish more earth than is required for the embankment, it is deposited in what is termed *spoil-bank*, on the side of the excavation. The spoil-bank should be made at some distance back from the side slope of the excavation, and on the down-hill side of the top surface; and suitable drains should be arranged to carry off any water that might collect near it and affect the side slope of the excavation.

The forms to be given to side-cuttings and spoil-banks will depend, in a great degree, upon the locality: they should, as far as practicable, be such that the cost of removal of the earth shall be least possible.

653. *Drainage.* A system of thorough drainage, by which the water that filters through the ground will be cut off from the soil beneath the roadway, to a depth of at least three feet below the bottom of the road-covering, and by which that which falls upon the surface will be speedily conveyed off, before it can filter through the road-covering, is essential to the good condition of a road.

The surface-water is conveyed off by giving the surface of the roadway a slight transverse convexity, from the middle to the sides, where the water is received into the gutters, or *side channels*, from which it is conveyed by underground aqueducts, termed *culverts*, built of stone or brick and usually arched at top, into the main drains that communicate with the natural water-courses. This convexity is regulated by making the figure of the profile

an ellipse, of which the semi-transverse axis is 15 feet, and the semi conjugate axis 9 inches; thus placing the middle of the roadway nine inches above the bottom of the side channels. This convexity, which is as great as should be given, will not be sufficient in a flat country to keep the road-surface dry; and in such localities, if a slight longitudinal slope cannot be given to the road, it should be raised, when practicable, three or four feet above the general level; both on account of conveying off speedily the surface-water, and exposing the surface better to the action of the wind.

To drain the soil beneath the roadway in a level country, ditches, termed *open side drains*, (Fig. 154,) are made parallel

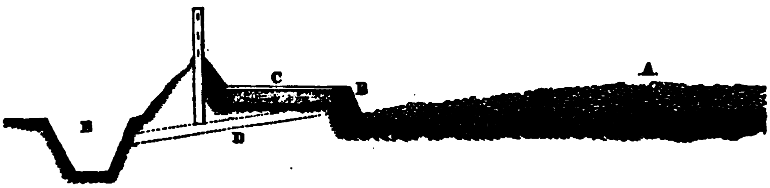


Fig. 154—Cross section of broken-stone road-covering.
A, road-surface.
B, side channels.
C, footpath.
D, covered drains, or culverts, leading from side channels to the side drains E.

to the road, and at some feet from it on each side. The bottom of the side drains should be at least three feet below the road-covering; their size will depend on the nature of the soil to be drained. In a cultivated country the side drains should be on the field side of the fences.

As open drains would be soon filled along the parts of a road in excavation, by the washings from the side slopes, covered drains, built either of brick or stone, must be substituted for them. These drains (Fig. 155) consist simply of a flooring of

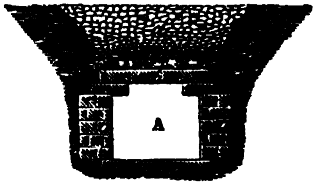


Fig. 155—Cross section of a covered drain.
A, drain.
a, *a*, side walls.
b, top stones.
c, bottom stones.
d, broken stone or large gravel laid over brush.

flagging stone, or of brick, with two side walls of rubble, or brick masonry, which support a top covering of flat stones, or of brick, with open joints, of about half an inch, to give a free passage way to the water into the drain. The top is covered with a layer of straw or brushwood; and clean gravel, or broken stone, in small fragments, is laid over this, for the purpose of allowing the

water to filter freely through to the drain, without carrying with it any earth or sediment, which might in time accumulate and choke it. The width and height of covered drains will depend on the materials of which they are built, and the quantity of water to which they yield a passage.

Besides the longitudinal covered drains in cuttings, other drains are made under the roadway which, from their form, are termed *cross mitre drains*. Their plan is in shape like the letter V, the angular point being at the centre of the road, and pointing in the direction of its ascent. The angle should be so regulated that the bottom of the drain shall not have a greater slope along either of its branches, than one perpendicular to one hundred base, to preserve the masonry from damage by the current. The construction of mitre drains is the same as the covered longitudinal drains. They should be placed at intervals of about 60 yards from each other.

In some cases surface drains, termed *catch-water drains*, are made on the side slopes of cuttings. They are run up obliquely along the surface, and empty directly into the cross drains which convey the water into the natural water-courses.

When the roadway is in side-forming, cross drains of the ordinary form of culverts are made, to convey the water from the side channels and the covered drains into the natural water-courses. They should be of sufficient dimensions to convey off a large volume of water, and to admit a man to pass through them so that they may be readily cleared out, or even repaired, without breaking up the roadway over them.

The only drains required for embankments are the ordinary side channels of the roadway, with occasional culverts, to convey the water from them into the natural water-courses. Great care should be taken to prevent the surface-water from running down the side slopes, as they would soon be washed into gullies by it.

Very wet and marshy soils require to be thoroughly drained before the roadway can be made with safety. The best system that can be followed in such cases, is to cut a wide and deep open main-drain on each side of the road, to convey the water to the natural water-courses. Covered cross drains should be made at frequent intervals, to drain the soil under the roadway. They should be sunk as low as will admit of the water running from them into the main drains, by giving a slight slope to the bottom each way from the centre of the road to facilitate its flow.

Independently of the drainage for marshy soils, they will require, when the subsoil is of a spongy, elastic nature, an artificial bed for the road-covering. This bed may, in some cases, be formed by simply removing the upper stratum to a depth of several feet, and supplying its place with well-packed gravel, or any

soil of a firm character. In other cases, when the subsoil yields readily to the ordinary pressure that the road-surface must bear, a bed of brushwood, from 9 to 18 inches in thickness, must be formed to receive the soil on which the road-covering is to rest The brushwood should be carefully selected from the long straight slender shoots of the branches or undergrowth, and be tied up in bundles, termed *fascines*, from 9 to 12 inches in diameter, and from 10 to 20 feet long. The fascines are laid in alternate layers crosswise and lengthwise, and the layers are either connected by pickets, or else the withes, with which the fascines are bound, are cut to allow the brushwood to form a uniform and compact bed.

This method of securing a good bed for structures on a weak wet soil has been long practised in Holland, and experience has fully tested its excellence.

654. *Road-coverings*. The object of a road-covering being to diminish the resistances arising from collision and friction, and thereby to reduce the force of traction to the least practicable amount, it should be composed of hard and durable materials, laid on a firm foundation, and present a uniform even surface.

The material in ordinary use for road-coverings is stone, either in the shape of blocks of a regular form, or of large round pebbles, termed a *pavement;* or broken into small angular masses; or in the form of gravel.

655. *Pavements*. The pavements in most general use in our country are constructed of rounded pebbles, known as *paving stones*, varying from 3 to 8 inches in diameter, which are set in a *form*, or bed of clean sand or gravel, a foot or two in thickness, which is laid upon the natural soil excavated to receive the form. The largest stones are placed in the centre of the roadway. The stones are carefully set in the form, in close contact with each other, and are then firmly settled by a heavy rammer until their tops are even with the general surface of the roadway, which should be of a slightly convex shape, having a slope of about $\frac{1}{48}$ from the centre each way to the sides. After the stones are driven, the road-surface is covered with a layer of clean sand, or fine gravel, two or three inches in thickness, which is gradually worked in between the stones by the combined action of the travel over the pavement and of the weather

The defects of pebble pavements are obvious, and confirmed by experience. The form of sand or gravel, as usually made, is not sufficiently firm; it should be made in separate layers of about 4 inches, each layer being moistened and well settled either by ramming, or passing a heavy roller over it. Upon the form prepared in this way a layer of loose material of two or three

inches in thickness may be placed, to receive the ends of the paving stones. From the form of the pebbles, the resistance to traction arising from collision and friction is very great.

Pavements termed *stone tramways* have been tried in some of the cities of Europe, both for light and heavy traffic. They are formed by laying two lines of long stone blocks for the wheels to run on, with a pavement of pebble for the horse-track between the wheel-tracks. In crowded thoroughfares tramways offer but few if any advantages, as it is impracticable to confine the vehicles to them, and when exposed to heavy traffic they wear into ruts. The stone blocks should be carefully laid on a very firm bottoming, and particular attention is requisite to prevent ruts from forming between the blocks and the pebble pavement.

Stone suitable for pavements should be hard and tough, and not wear smooth under the action to which it is exposed. Some varieties of granite have been found in England to furnish the best paving blocks. In France, a very fine-grained compact gray sandstone of a bluish cast is mostly in use for the same purpose, but it wears quite smooth.

The sand used for forms should be clean and free from pebbles and gravel of a larger grain than about two tenths of an inch. The form should be made by moistening the sand, and compressing it in layers of about four inches in thickness, either by ramming, or by passing over each layer several times a heavy iron roller. Upon the top layer about an inch of loose sand may be spread to receive the blocks; the joints between which, after they are placed, should be carefully filled with sand.

The sand form, when carefully made, presents a very firm and stable foundation for the pavement.

Wooden pavements, formed of blocks of wood of various shapes, have been tried in England and several of our cities within the last few years, but are now for the most part abandoned, as the material has been found to decay very rapidly, even when prepared with some of the preservatives of timber against the rot.

Asphaltic pavements have undergone a like trial, and have also been found to fail after a few years service. This material is farther objectionable as a pavement in cities where the pavements and sidewalks have frequently to be disturbed for the purposes of repairing, or laying down sewers, water-pipes, and other necessary conveniences for a city.

The best system of pavement is that which has been partially put in practice in some of the commercial cities of England, the idea of which seems to have been taken from the excellent military roads of the Romans, vestiges of which remain at the present day in a good state.

In constructing this pavement, a bed (Fig. 156) is first pre pared, by removing the surface of the soil to the depth of a foo or more, to obtain a firm stratum; the surface of this bed re

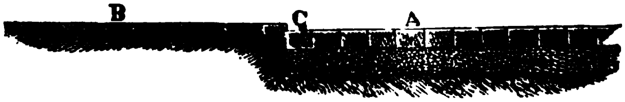


Fig. 156—Paved road-covering.
A, pavement.
C, curb-stone.
B, flagging of side-walk.

ceives a very slight convexity, of about two inches to ten feet, from the centre to the sides of the roadway. If the soil is of a soft clayey nature, into which small fragments of broken stone would be easily worked by the wheels of vehicles, it should be excavated a foot or two deeper to receive a form of sand, or of clean fine gravel. On the surface of the bed thus prepared, a layer of small broken stone, four inches thick, is laid; the dimensions of these fragments should not be greater than two and a half inches in any direction; the road is then opened to vehicles until this first layer becomes perfectly compact; care being taken to fill up any ruts with fresh stone, in order to obtain a uniform surface. A second layer of stone, of the same thickness as the first, is then laid on, and treated in the same manner; and finally a third layer. When the third layer has become perfectly compact, and is of a uniform surface, a layer of fine clean gravel, two and a half inches thick, is spread evenly over it to receive the paving stones. The blocks of stone are of a square shape, and of different sizes, according to the nature of the travelling over the pavement. The largest size are ten inches thick, nine inches broad, and twelve inches long; the smallest are six inches thick, five inches broad, and ten inches long. Each block is carefully settled in the form, by means of a heavy beetle; it is then removed in order to cover the side of the one against which it is to rest with hydraulic mortar; this being done, the block is replaced, and properly adjusted. The blocks of the different courses across the roadway should break joints. The surface of the road is convex; the convexity being determined by making the outer edges six inches lower than the middle, for a width of thirty feet.

This system of pavement fulfils in the best manner all the requisites of a good road-covering, presenting a hard even surface to the action of the wheels, and reposing on a firm bed formed by the broken-stone bottoming. The mortar-joints, so long as they remain tight, will effectually prevent the penetration of water beneath the pavement; but it is probable, from the effect of the transit of heavily-laden vehicles, and from the expansion and

contraction of the stone, which in our climate is found to be very considerable, that the mortar would soon be crushed and washed out.

In France, and in many of the large cities of the continent, the pavements are made with blocks of rough stone of a cubical form measuring between eight and nine inches along the edge of the cube. These are laid on a form of sand of only a few inches thick when the soil beneath is firm; but in bad soils the thickness is increased to from six to twelve inches. The transversal joints are usually continuous, and those in the direction of the axis of the road break joints. In some cases the blocks are so laid that the joints make an angle of 45° with the axis of the roadway, one set being continuous, the other breaking joints with them. By this arrangement of the joints, it is said that the wear upon the edges of the blocks, by which the upper surface soon assumes a convex shape, is diminished. It has been ascertained by experience, that the wear upon the edges of the blocks is greatest at the joints which run transversely to the axis when the blocks are laid in the usual manner. From the experiments of M. Morin, to ascertain the influence of the shape of stone blocks on the force of traction, it was found that the resistance offered by a pavement of blocks averaging from five to six inches in breadth, measured in the direction of the axis of the roadway, and about nine inches in length, was less than in one of cubical blocks of the ordinary size.

Pavements in cities must be accompanied by sidewalks, and crossing-places, for foot-passengers. The sidewalks are made of large flat flagging-stone, at least two inches thick, laid on a form of clean gravel well rammed and settled. The width of the sidewalks will depend on the street being more or less frequented by a crowd. It would, in all cases, be well to have them at least twelve feet wide; they receive a slope, or pitch, of one inch to ten feet, towards the pavement, to convey the surface-water to the side channels. The pavement is separated from the sidewalk by a row of long slabs set on their edges, termed *curb-stones*, which confine both the flagging and paving stones. The curb-stones form the sides of the side channels, and should for this purpose project six inches above the outside paving stones, and be sunk at least four inches below their top surface; they should, moreover, be flush with the upper surface of the side-walks, to allow the water to run over into the side channels, and to prevent accidents which might otherwise happen from their tripping persons passing in haste.

The crossings should be from four to six feet wide, and be slightly raised above the general surface of the pavement, to keep them free from mud.

656. *Broken-stone road-covering.* The ordinary road-covering for common roads, in use in this country and Europe, is formed of a coating of stone broken into small fragments, which is laid either upon the natural soil, or upon a paved bottoming of small irregular blocks of stone. In England these two systems have their respective partisans; the one claiming the superiority for road-coverings of stone broken into small fragments, a method brought into vogue some years since by Mr. McAdam, from whom these roads have been termed *macadamized;* the other being the plan pursued by Mr. Telford in the great national roads constructed in Great Britain within about the same period.

The subject of road-making has within the last few years excited renewed interest and discussion among engineers in France; the conclusion, drawn from experience, there generally adopted is, that a covering alone of stone broken into small fragments is sufficient under the heaviest traffic and most frequented roads. Some of the French engineers recommend, in very yielding clayey soils, that either a paved bottoming after Telford's method be resorted to, or that the soil be well compressed at the surface before placing the road-covering.

The paved bottom road-covering on Telford's plan (Fig. 155) is formed by excavating the surface of the ground to a suitable depth, and preparing the form for the pavement with the precautions as for a common pavement. Blocks of stone of an irregular pyramidal shape are selected for the pavement, which, for a roadway 30 feet in width, should be seven inches thick for the centre of the road, and three inches thick at the sides. The base of each block should not measure more than five inches, and the top not less than four inches.

The blocks are set by the hand, with great care, as closely in contact at their bases as practicable; and blocks of a suitable size are selected to give the surface of the pavement a slightly convex shape from the centre outwards. The spaces between the blocks are filled with chippings of stone compactly set with a small hammer.

A layer of broken stone, four inches thick, is laid over this pavement, for a width of nine feet on each side of the centre; no fragment of this layer should measure over two and a half inches in any direction. A layer of broken stone of smaller dimensions, or of clean coarse gravel, is spread over the wings to the same depth as the centre layer.

The road-covering, thus prepared, is thrown open to vehicles until the upper layer has become perfectly compact; care having been taken to fill in the ruts with fresh stone, in order to obtain a uniform surface. A second layer, about two inches in depth is then laid over the centre of the roadway; and the wings re

ceive also a layer of new material laid on to a sufficient thickness to make the outside of the roadway nine inches lower than the centre, by giving a slight convexity to the surface from the centre outwards. A coating of clean coarse gravel, one inch and a half thick, termed a *binding*, is spread over the surface, and the road-covering is then ready to be thrown open to travelling.

The stone used for the pavement may be of an inferior quality in hardness and strength, to that placed at the surface, as it is but little exposed to the wear and tear occasioned by travelling. The surface-stone should be of the hardest kind that can be procured The gravel binding is laid over the surface to facilitate the travelling, whilst the under stratum of stone is still loose; it is, however, hurtful, as, by working in between the broken stones, it prevents them from setting as compactly as they would otherwise do.

If the roadway cannot be paved the entire width, it should, at least, receive a pavement for the width of nine feet on each side of the centre. The wings, in this case, may be formed entirely of clean gravel, or of chippings of stone.

For roads which are not much travelled, like the ordinary cross roads of the country, the pavement will not demand so much care; but may be made of any stone at hand, broken into fragments of such dimensions that no stone shall weigh over four pounds. The surface-coating may be formed in the manner just described.

657. In forming a road-covering of broken stone alone, the bed for the covering is arranged in the same manner as for the paved bottoming: a layer of the stone, four inches in thickness, is carefully spread over the bed, and the road is thrown open to vehicles, care being taken to fill the ruts, and preserve the surface in a uniform state until the layer has become compact; successive layers are laid on and treated in the same manner as the first, until the covering has received a thickness of about twelve inches in the centre, with the ordinary convexity at the surface.

658. Where good gravel can be procured the road-covering may be made of this material, which should be well screened, and all pebbles found in it over two and a half inches in diameter should be broken into fragments of not greater dimensions than these. A firm level form having been prepared, a layer of gravel, four inches in thickness, is laid on, and, when this has become compact from the travel, successive layers of about three inches in thickness are laid on and treated like the first, until the covering has received a thickness of sixteen inches in the centre and the ordinary convexity.

659. As has been already stated, the French civil engineers

do not regard a paved bottoming as essential for broken-stone road-coverings, except in cases of a very heavy traffic, or where the substratum of the road is of a very yielding character. They also give less thickness to the road-covering than the English engineers of Telford's school deem necessary; allowing not more than six to eight inches to road-coverings for light traffic, and about ten inches only for the heaviest traffic.

660. If the soil upon which the road-covering is to be placed is not dry and firm, they compress it by rolling, which is done by passing over it several times an iron cylinder, about six feet in diameter, and four feet in length, the weight of which can be increased, by additional weights, from six thousand to about twenty thousand pounds. The road material is placed upon the bed, when well compressed and levelled, in layers of about four inches, each layer being compressed by passing the cylinder several times over it before a new one is laid on. If the operation of rolling is performed in dry weather, the layer of stone is watered, and some add a thin layer of clean sand, from four to eight tenths of an inch in thickness, over each layer before it is rolled, for the purpose of consolidating the surface of the layer, by filling the voids between the broken-stone fragments. After the surface has been well consolidated by rolling, the road is thrown open for travel, and all ruts and other displacement of the stone on the surface are carefully repaired, by adding fresh material, and levelling the ridges by ramming.

Great importance is attached by the French engineers to the use of the iron cylinder for compressing the materials of a new road, and to minute attention to daily repairs. It is stated that by the use of the cylinder the road is presented at once in a good travelling condition; the wear of the materials is less than by the old method of gradually consolidating them by the travel; the cost of repairs during the first years is diminished; it gives to the road-covering a more uniform thickness, and admits of its being thinner than in the usual method.

661. *Materials and Repairs.* The materials for broken-stone roads should be hard and durable. For the bottom layer a soft stone, or a mixture of hard and soft may be used, but on the surface none but the hardest stone will withstand the action of the wheels. The stone should be carefully broken into fragments of nearly as cubical a form as practicable, and be cleansed from dirt and of all very small fragments. The broken stone should be kept in depots at convenient points along the line of the road for repairs.

Too great attention cannot be bestowed upon keeping the road-surface free from an accumulation of mud and even of dust. It should be constantly cleaned by scraping and sweeping. The

repairs should be daily made by adding fresh material upon all points where hollows or ruts commence to form. It is recommended by some that when fresh material is added, the surface on which it is spread should be broken with a pick to the depth of half an inch to an inch, and the fresh material be well settled by ramming, a small quantity of clean sand being added to make the stone pack better. When not daily repaired by persons whose sole business it is to keep the road in good order, general repairs should be made in the months of October and April, by removing all accumulations of mud, cleaning out the side channels and other drains, and adding fresh material where requisite.

The importance of keeping the road-surface at all times free from an accumulation of mud and dust, and of preserving the surface in a uniform state of evenness, by the daily addition of fresh material wherever the wear is sufficient to call for it, cannot be too strongly insisted upon. Without this constant supervision, the best constructed road will, in a short time, be unfit for travel, and with it the weakest may at all times be kept in a tolerably fair state

662. *Cross dimensions of roads.* A road thirty feet in width is amply sufficient for the carriage-way of the most frequented thoroughfares between cities. A width of forty, or even sixty feet, may be given near cities, where the greater part of the transportation is effected by land. For cross roads, and others of minor importance, the width may be reduced according to the nature of the case. The width should be at least sufficient to allow two of the ordinary carriages of the country to pass each other with safety. In all cases, it should be borne in mind, that any unnecessary width increases both the first cost of construction, and the expense of annual repairs.

Very wide roads have, in some cases, been used, the centre part only receiving a road-covering, and the wings, termed *summer roads*, being formed on the natural surface of the subsoil. The object of this system is to relieve the road-covering from the wear and tear occasioned by the lighter kind of vehicles during the summer, as the wings present a more pleasant surface for travelling in that season. But little is gained by this system under this point of view; and it has the inconvenience of forming during the winter a large quantity of mud which is very injurious to the road-covering.

There should be at least one foot-path, from five to six feet wide, and not more than nine inches higher than the bottom of the side channels. The surface of the foot-path should have a pitch of two inches, towards the side channels, to convey its surface water into them. When the natural soil is firm and

sandy, or gravelly, its surface will serve for the foot-path; but in other cases the natural soil must be thrown out to a depth of six inches, and the excavation be filled with fine clean gravel.

To prevent the foot-path from being damaged by the current of water in the side channels, its side slope, next to the side channel, must be protected by a facing of good sods, or of dry stone.

As it is of the first importance, in keeping the road-way in a good travelling state, that its surface should be kept dry, it will be necessary to remove from it, as far as practicable, all objects that might obstruct the action of the wind and the sun on its surface. Fences and hedges along the road should not be higher than five feet; and no trees should be suffered to stand on the road-side of the side drains, for independently of shading the road-way, their roots would in time throw up the road-covering.

See Note B., Appendix.

RAILWAYS

663. The great resistance offered to the force of traction on common roads, where the traffic is of a heavy character, naturally suggested the idea of trying other means, which would afford a more even and durable track for the wheels than the road-coverings in ordinary use. Various methods have been resorted to, with greater or less success, to accomplish this object: in some instances tracks have been formed of long narrow stone blocks; in others, heavy beams of timber, covered on the surface with sheet iron to protect them from wear, have been used; and finally, both the stone and wooden ways were replaced by iron plates and bars, and that system of road-covering, now so well known as the railway, or railroad, has been the result.

For these successive stages of improvement, by which, in the short period of less than a quarter of a century, so great a revolution has been made both in the speed and the amount of transportation on land, by means which bid fair to supersede every other, the civilized world is indebted to England, in whose mining districts the railway system first sprung up.

664. A *railway*, or *railroad*, is a track for the wheels of vehicles to run on, which is formed of iron bars placed in two parallel lines and resting on firm supports.

665. *Rails.* The iron ways first laid down, and termed *tramways*, were made of narrow iron plates, cast in short lengths, with an upright flanch on the exterior to confine the wheel within the track. The plates were found to be deficient in strength, and were replaced by others to which a vertical rib was added under the plate. This rib was of uniform breadth, and of the shape of a semi-ellipse in elevation. This form of tramway, although superior in strength to the first, was still found not to work well, as the mud which accumulated between the flanch and the surface of the plate presented a considerable resistance to the force of traction. To obviate this defect, iron bars of a semi-elliptical shape in elevation, which received the name of

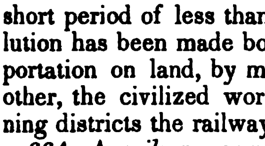


Fig. 157—Represents a cross section *a*, of the fish-bellied rail of the Liverpool and Manchester Railway, and the method in which it is secured to its chair The rail is formed with a slight projection at bottom, which fits into a corresponding notch in the side of the chair *b*. An iron wedge *c* is inserted into a notch on the opposite side of the chair, and confines the rail in its place.

edge rails, were substituted for the plates of the tramway. The cross sections of these rails were of the form shown in Fig. 157,

the top surface being slightly convex, and sufficiently broad to preserve the tire of the wheel from wearing unevenly. This change in the form of the rail introduced a corresponding one in the tires of the wheels, which were made with a flanch on the interior to confine them within the rails of the track.

The cast-iron edge-rail was found upon trial to be subject to many defects, arising from the nature of the material. As it was necessary to cast the rails in short lengths of three or four feet, the track presented a number of joints, which rendered it extremely difficult to preserve a uniform surface. The rails were found to break readily, and the surface upon which the wheels ran wore unevenly. These imperfections finally led to the substitution of wrought-iron for cast-iron.

666. The wrought-iron rails first brought into use received nearly the same shape in cross section and elevation as the cast iron rail. They were formed by rolling them out in a rolling-mill so arranged as to give the rail its proper shape. The length of the rail was usually fifteen feet, the bottom of it (Fig. 158)

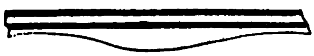


Fig. 158—Represents a side elevation of a portion of a fish-bellied rail.

presenting an undulating outline so disposed as to give the rail a bearing point on supports placed three feet apart between their centres. This form, known as the *fish-belly* rail, was adopted as presenting the greatest strength for the same amount of metal. It has been found on trial to be liable to some inconveniences. The rails break at about nine inches from the supports, or one fourth of the distance between the bearing points, and from the curved form of the bottom of the rail they do not admit of being supported throughout their length.

667. The form of rail at present in most general use is known by the name of the *parallel*, or *straight* rail, the top and bottom of the rail being parallel; or as the T, or H rail, from the form of the cross section.

A variety of forms of cross section are to be met with in the parallel rail. The more usual form is that (Fig. 159) in which

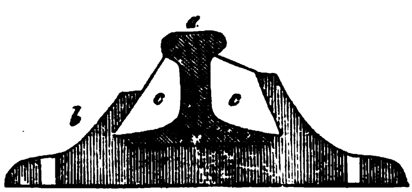


Fig. 159—Represents a cross section *a* of a parallel rail of the form generally adopted in the U. States. The rail is confined to its chair *b* by two wooden keys *c* on each side, which are formed of hard compressed wood.

the top is shaped like the same part in the fish-belly rail, the bottom being widened out to give the rail a more stable seat on

its supports. In some cases the top and bottom are made alike to admit of turning the rail. The greatest deviation from the usual form is in the rail of the Great Western Railway in England, (Fig. 160.)



Fig. 160—Represents a cross section of the rail of the Great Western Railway in England. This rail is laid on a continuous support, and is fastened to it by screws on each side of the rail. A piece of tarred felt was inserted between the base of the rail and its support.

The dimensions of the cross section of a rail should be such that the deflection in the centre between any two points of support, caused by the heaviest loads upon the track, should not be so great as to cause any very appreciable increase of resistance to the force of traction. The greatest deflection, as laid down by some writers, should not exceed three hundredths of an inch, for the usual bearing of three feet between the points of support. The top of the rail is usually about two and a half inches broad, and an inch in depth. This has been found to present a good bearing surface for the wheels, and sufficient strength to prevent the top from being crushed by the weight upon the rail. The breadth of the rib varies between three fourths of an inch to an inch; and the total depth of the rail from three to five inches. The thickness and breadth of the bottom have been varied according to the strength and stability demanded by the traffic.

668. *Supports.* The rails are laid upon supports of timber, or stone. The supports should present a firm unyielding bed to the rails, so as to prevent all displacement, either in a lateral or a vertical direction, from the pressure thrown upon them.

Considerable diversity is to be met with in the practice of engineers on this point. On the earlier roads, heavy stone blocks were mostly used for supports, but these were found to require great precautions to render them firm, and they were, moreover, liable to split from the means taken to confine the rails to them. Timber has, within late years, been generally preferred to stone. It affords a more agreeable road for travel, and gives a better lateral support to the rails than stone blocks.

The usual method of placing timber supports is transversely to the track. Each support, termed a *sleeper*, or *cross-tie*, being formed of a piece of timber six or eight inches square. The ordinary distance between the centre lines of the supports, is three feet for rails of the usual dimensions. With a greater bearing, rails of the ordinary dimensions do not present sufficient stiffness. The sleepers, when formed of round timber, should be squared on the upper and lower surface. On some of the recent railways in England, sleepers presenting in cross section a right-angled triangle have been used, the right angle being at the bottom. They are represented to be more convenient in setting, and to

offer a more stable support than those of the usual form. The sleepers are placed either upon the ballasting of the roadway, or upon longitudinal beams laid beneath them along the line of the rails. The latter is now the more usual practice with us, and is indispensable upon new embankments to prevent the ends of the sleepers from settling unequally. Thick plank, about eight inches broad and three or four inches thick, is usually employed for the longitudinal supports of the sleepers.

On some of the more recent railways in England, the rails have been laid upon longitudinal beams, presenting a continuous support to the rail, the beams resting upon cross-ties.

669. *Chairs.* The rails are firmly fastened to their supports by cast-iron *chairs*, (Figs. 157, 159,) wrought-iron spikes, or screws. The chair is cast in one piece, and consists of a bottom-plate, upon which the rail rests, and two side pieces between which the rail is confined by wedges of iron, or of wood. The chairs are fastened to the supports by iron bolts, or wooden pins. A variety of forms have been given to the chairs, and different methods adopted for confining the rail firmly within them. Iron wedges having been found to work loose, wooden wedges, or keys, have been substituted for them. They are made of kiln-dried timber, and are forced through cutters, by which they receive the proper shape, and are at the same time strongly compressed. The key, prepared in this manner, gradually swells by imbibing moisture after being inserted, and forms a very strong fastening. Chairs are generally placed upon each support. In some cases they are only placed at the points of junction of the rails; iron spikes with a bent head being driven into the supports, to confine the rails at the intermediate points between the chairs.

A joint of sufficient width is left between the ends of the rails, to allow for the expansion of the bars. Various methods of forming this joint have been tried; the more usual forms are the square joint, and the oblique joint.

670. *Ballast.* A covering of broken stone, of clean coarse gravel, or of any other material that will allow the water to drain off freely, is laid upon the natural surface of the excavations and embankments, to form a firm foundation for the supports. This has received the appellation of the *ballast*. Its thickness is from nine to eighteen inches. Open or broken-stone drains should be placed beneath the ballasting to convey off the surface water. The parts of the ballasting upon which the supports rest should be well rammed, or rolled; and it should be well packed beneath and around the supports. After the rails are laid, another layer of broken stone or gravel should be added the surface of which should be slightly convex and about three inches below the top of the rails.

671. *Temporary railways of wood and iron.* On the first introduction of railways into the United States, the tracks were formed of flat iron bars laid upon longitudinal beams. The iron bars were about two and a half inches in breadth, and from one half to three fourths of an inch in thickness, the top surface being slightly convex. They were placed on the longitudinal beams, a little back from the inner edge, the side of the beam near the top being bevelled off, and were fastened to the beam by screws or spikes, which passed through elliptical holes with a countersink to receive the heads of the spikes; the holes receiving this shape to allow of the contraction and expansion of the bar, without displacing the fastenings. The longitudinal beams were supported by cross sleepers, with which they were connected by wedges that confined the beams in notches cut into the sleepers to receive them. The longitudinal beams were usually about six inches in breadth, and nine inches in depth, and in as long lengths as they could be procured. The joints between the bars were either square or oblique, and a piece of iron or zinc was inserted into the beams at the joint, to prevent the end of the rail from being crushed into the wood by the wheels.

In some instances the bars were fastened to long stone blocks, but this method was soon abandoned, as the stone was rapidly destroyed by the action of the wheels; besides which, the rigid nature of the stone rendered the travelling upon it excessively disagreeable.

This system of railway, whose chief recommendation is economy in the first cost, has gradually given place to the solid rail. Besides the want of durability of the structure, it does not possess sufficient strength for a heavy traffic.

672. *Gauge.* The distance between the two lines of rails of a track, termed the *gauge*, which has been adopted for the great majority of the railways in England, and also with us, is 4 feet 8½ inches. This gauge appears to have been the result of chance, and it has been followed in the great majority of cases up to the present time, owing to the inconvenience that would arise from the adoption of a different gauge upon new lines. The greatest deviation yet made from the established gauge is in that of the Great Western Railway, in which the gauge is seven feet. Engineers are generally agreed that a wider gauge is desirable, as with it the wheels of railway cars could be made of greater diameter than they now receive, and be placed outside of the cars instead of under them as at present; the centre of gravity of the load might be placed lower, and more steadiness of motion and greater security at high velocities be attained.

In a double track the distance between the two tracks is generally the same as the gauge; and the distance between the outside rail of a track, and the sides of the excavation, or embankment, is seldom made greater than six feet, as this is deemed sufficient to prevent the cars from going over an embankment were they to run off the rails.

673. On all straight portions of a track, the supports should be on a level transversely, and parallel to the plane of the track longitudinally. The top surface of the rail should incline inward, to conform to the conical form of the wheels; this is now usually effected by giving the chair the requisite pitch, or by forming the top surface with the requisite bevel for this purpose.

674. *Curves.* In the curved portions of a track the centrifugal force tends to force the carriage towards the outside rail of the curve. This action of the centrifugal force is counteracted, to a certain extent, by the conical form of the wheels, which, by causing them to run on unequal diameters so soon as they enter a curve, inclines the car inward. Within certain limits of the radius of curvature, the amount of the force by which the car is impelled towards the centre of the curve, by this change in the diameter of the interior and exterior wheels, will be sufficient to counteract the centrifugal force which urges it outward. With wheels of the diameter and shape at present in general use, the usual gauge of track, and play between the flanch of each wheel and the side of the rail, the least radius of curvature which will prevent the flanch of the exterior wheel from being brought into contact with the side of the rail, is found to be about 600 feet. To prevent actual contact and offer perfect security, the radius allowed should not be less than 1000 feet, when the exterior and interior rails are on the same level transversely. As on curves with a smaller radius than 1000 feet, the flanch of the wheel might be driven against the rail, and the car be forced from the track, it will be requisite to provide against this by raising the exterior rail higher than the interior, so that by thus placing the wheels on an inclined plane, the component of gravity, opposed to the centrifugal force, added to the force which impels the car inward when running on wheels of unequal diameter, may balance the centrifugal force. From the above conditions of equilibrium, the elevation which the exterior rail should receive above the interior can be readily calculated. The method more usually adopted, however, is to neglect the effect of the conical form of the wheel, in counteracting the action of the centrifugal force within certain limits, and to give the exterior rail an elevation sufficient to prevent the flanch of the wheel from being driven against the side of the rail

when the car is moving at the highest supposed velocity; or, in other words, to give the inclined plane across the track, on which the wheels rest, an inclination such that the tendency of the wheels to slide towards the interior rail shall alone counteract the centrifugal force.

675. *Sidings, &c.* On single lines of railways short portions of a track, termed *sidings*, are placed at convenient intervals along the main track, to enable cars going in opposite directions to cross each other, one train passing into the siding and stopping while the other proceeds on the main track. On double lines arrangements, termed *crossings*, are made to enable trains to pass from one track into the other, as circumstances may require. The position of sidings and their length will depend entirely on local circumstances, as the length of the trains, the number daily, &c.

The manner generally adopted, of connecting the main track with a siding, or a crossing, is very simple. It consists (Fig. 161) in having two short lengths of the opposite rails of the main

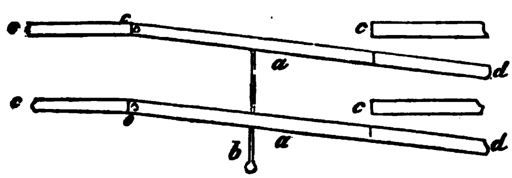


Fig. 161—Represents the sliding switches, or rails, for connecting a siding with the main track.
a, a, rails connected by an iron rod *b*, by which they can be turned around the joints *o, o*.
c, c, rails of main track.
d, d, rails of siding.

track, where the siding or crossing joins it, moveable around one of their ends, so that the other can be displaced from the line of the main track, and be joined with that of the siding, or crossing, on the passage of a car out of the main track. These moveable portions of rails are connected and kept parallel by a long cross

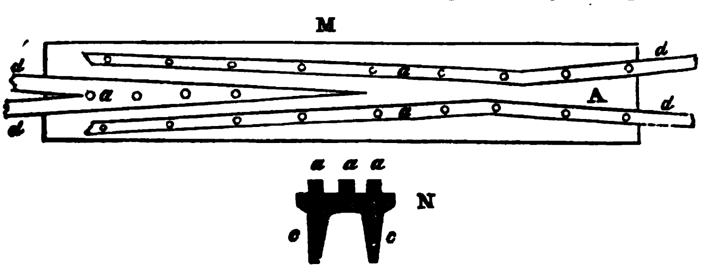


Fig. 162—Represents a plan M, and section N, of a fixed crossing plate. The plate A is of cast-iron, with vertical ribs *c, c*, on the bottom, to give it the requisite strength. Wrought-iron bars *a, a*, placed in the lines of the two intersecting rails *d, d*, are firmly screwed to the plate; a sufficient space being left between them and the rails for the flanch of the wheel to pass.

bolt, to the end of which a vertical lever is attached to draw them forward, or shove them back.

At the point where the rails of the two tracks intersect, a cast iron plate, termed a *crossing-plate* (Fig. 162) is placed to con nect the rails. The surface of the plate is arranged either with grooves in the lines of the rails to admit the flanch of the wheel in passing, the tire running upon the surface of the plate; or wrought-iron bars are affixed to the surface of the plate for the same purpose.

The angle between the rails of the main tracks and those of a siding or crossing, termed the *angle of deflection*, should not be greater than 2° or 3°. The connecting rails between the straight portions of the tracks should be of the shape of an S curve, in order that the passage may be gradually effected.

676. *Turn-plates.* Where one track intersects another under a considerable angle, it will be necessary to substitute for the ordinary method of connecting them, what is termed a *turn-plate*, or turn-table. This consists of a strong circular platform of wood or cast-iron, moveable around its centre by means of conical rollers beneath it running upon iron roller-ways. Two rails are laid upon the platform to receive the car, which is transferred from one track to the other by turning the platform sufficiently to place the rails upon it in the same line as those of the track to be passed into.

677. *Street-crossings.* When a track intersects a road, or street, upon the same level with it, the rail must be guarded by cast-iron plates laid on each side of it, sufficient space being left between them and the rail for the play of the flanch. The top of the plates should be on a level with the top of the rail. Wherever it is practicable a drain should be placed beneath, to receive the mud and dust which, accumulating between the plates and rail, might interfere with the passing of the cars along the rails.

678. *Gradients.* From various experiments upon the friction of cars upon railways, it appears that the angle of repose is about $\frac{1}{250}$, but that in descending gradients much steeper, the velocity due to the accelerating force of gravity soon attains its greatest limit and remains constant, from the resistance caused by the air.

The limit of the velocity thus attained upon gradients of any degree, whether the train descends by the action of gravity alone, or by the combined action of the motive power of the engine and gravity, can be readily determined for any given load. From calculation and experiment it appears that heavy trains may descend gradients of $\frac{1}{100}$, without attaining a greater velocity than about 40 or 50 miles an hour, by allowing them to run freely

without applying the brake to check the speed. By the application of the brake, the velocity may be kept within any limit of safety upon much steeper gradients. The only question, then, in comparing the advantages of different gradients, is one of the comparative cost between the loss of power and speed, on the one hand, for ascending trains on steep gradients, and that of the heavy excavations, tunnels, and embankments, on the other, which may be required by lighter gradients.

In distributing the gradients along a line, engineers are generally agreed that it is more advantageous to have steep gradients upon short portions of the line, than to overcome the same difference of level by gradients less steep upon longer developments.

679. In steep gradients, where locomotive power cannot be employed, stationary power is used, the trains being dragged up, or lowered, by ropes connected with a suitable mechanism, worked by stationary power placed at the top of the plane. The inclined planes, with stationary power, generally receive a uniform slope throughout. The portion of the track at the top and bottom of the plane, should be level for a sufficient distance back, to receive the ascending or descending trains. The axes of the level portions should, when practicable, be in the same vertical plane as that of the axis of the inclined plane.

Small rollers, or sheeves, are placed at suitable distances along the axis of the inclined plane, upon which the rope rests.

Within a few years back flexible bands of rolled hoop-iron have been substituted for ropes on some of the inclined planes of the United States, and have been found to work well, presenting more durability and being less expensive than ropes.

680. *Tunnels.* The great consumption of power by gravity, and the necessity therefore of either employing additional power, or of diminishing the load of locomotives in ascending steep gradients, have caused engineers to resort to excavations and embankments frequently of excessive dimensions, to obtain gradients upon which the ordinary loads on a level can be transported with a suitable degree of speed. The difficulty and cost of forming these works become in some cases so great, that it is found preferable to obtain the requisite gradient by carrying the road under ground by an excavation termed a *tunnel.*

The choice between deep cutting and tunnelling, will depend upon the relative cost of the two, and the nature of the ground. When the cost of the two methods would be about equal, and the slopes of the deep cut are not liable to slips, it is usually more advantageous to resort to deep cutting than to tunnelling. So much, however, will depend upon local circumstances, that the comparative advantages of the two methods can only be de

cided upon understandingly when these are known Where any latitude of choice of locality is allowed, the nature of the soil, the length of the tunnel, that of the deep cuts by which it must be approached, and also the depths of the working and air shafts, must all be well studied before any definitive location is decided upon. In some cases it may be found, that a longer tunnel with shorter deep cuts will be more advantageous in one position, than a shorter tunnel with longer deep cuts in another. In others, the greater depth of working shafts may be more than compensated by obtaining a safer soil, or a shorter tunnel.

681. The operations in tunnelling will depend upon the nature of the soil. The work is commenced by setting out, in the first place, with great accuracy upon the surface of the ground, the profile line contained in the vertical plane of the axis of the tunnel. At suitable intervals along this line vertical pits, termed *working shafts*, are sunk to a level with the top, or crown of the tunnel. The shafts and the excavations, which form the entrances to the tunnel, are connected, when the soil will admit of it, by a small excavation termed a *heading*, or *drift*, usually five or six feet in width, and seven or eight feet in height, which is made along the crown of the tunnel. After the drift is completed, the excavation for the tunnel is gradually enlarged; the excavated earth is raised through the working shafts, and at the same time carried out at the ends. The dimensions and form of the cross section of the excavation, will depend upon the nature of the soil, and the object of the tunnel as a communication. In solid rock the sides of the excavation are usually vertical; the top receives an arched form; and the bottom is horizontal. In soils which require to be sustained by an arch, the excavation should conform as nearly as practicable to the form of cross section of the arch.

In tunnels through unstratified rocks, the sides and roof may be safely left unsupported; but in stratified rocks there is danger of blocks becoming detached and falling: wherever this is to be apprehended, the top of the tunnel should be supported by an arch.

Tunnelling in loose soils is one of the most hazardous operations of the miner's art, requiring the greatest precautions in supporting the sides of the excavations by strong rough framework, covered by a sheathing of boards, to secure the workmen from danger. When in such cases the drift cannot be extended throughout the line of the tunnel, the excavation is advanced only a few feet in each direction from the bottom of the working shafts, and is gradually widened and deepened to the proper form and dimensions to receive the masonry of the tunnel, which is immediately commenced below each working shaft, and is

carried forward in both directions towards the two ends of the tunnel.

682. *Masonry of tunnels.* The cross section of the arch of a tunnel (Fig. 163) is usually an oval segment, formed of arcs of

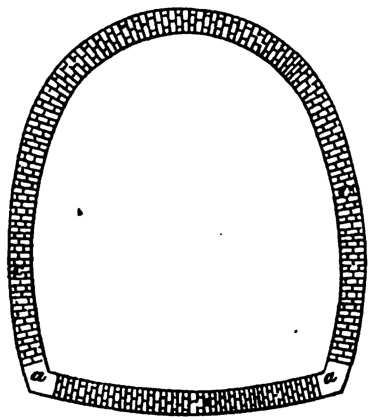


Fig. 163—Represents the general form of the cross section *c* of a brick arch for tunnels.
a, *a*, askew-back stone between the sides of the arch and the bottom inverted arch.

circles for the sides and top, resting on an inverted arch at bottom. The tunnels on some of the recent railways in England are from 24 to 30 feet wide, and of the same height from the level of the rails to the crown of the arch. The usual thickness of the arch is eighteen inches. Brick laid in hydraulic cement is generally used for the masonry, an askew back course of stone being placed at the junction of the sides and the inverted arch. The masonry is constructed in short lengths of about twenty feet, depending, however, upon the precautions necessary to secure the sides of the excavation. As the sides of the arch are carried up, the frame-work supporting the earth behind is gradually removed, and the space between the back of the masonry and the sides of the excavation is filled in with earth well rammed. This operation should be carefully attended to throughout the whole of the backing of the arch, so that the masonry may not be exposed to the effects of any sudden yielding of the earth around it.

683. The frame-work of the centres should be so arranged that they may be taken apart and be set up with facility. The combination adopted will depend upon the size of the arch, and the necessity of supporting the sides as well as the top of the arch by the centre, during the process of the work.

684. The earth at the ends of the tunnel is supported by a retaining wall, usually faced with stone. These walls, termed the *fronts* of the tunnel, are generally finished with the usual

architectural designs for gateways. To secure the ends of the arch from the pressure of the earth above them, cast-iron plates, of the same shape and depth as the top of the arch, are inserted within the masonry, a short distance from the ends, and are secured by wrought-iron rods firmly anchored to the masonry at some distance from each end.

685. The working shafts, which are generally made cylindrical and faced with brick, rest upon strong curbs of cast-iron, inserted into the masonry of the arch. The diameter of the shaft within is ordinarily nine feet.

Small shafts, about three feet in diameter, termed *air shafts*, are in some cases required at intermediate points between the working shafts, for the purposes of ventilation.

686. The ordinary difficulties of tunnelling are greatly increased by the presence of water in the soil through which the work is driven. Pumps, or other suitable machinery for raising water, placed in the working shafts, will in some cases be requisite to keep them and the drift free from water until an outlet can be obtained for it at the ends, by a drain along the bottom of the drift. Sometimes, when the water is found to gain upon the pumps at some distance above the level of the crown of the tunnel, an outlet may be obtained for it by driving above the tunnel a drift-way between the shafts, giving it a suitable slope from the centre to the two extremities to convey the water off rapidly.

In tunnels for railways, a drain should be laid under the ballasting along the axis, upon the inverted arch of the bottom.

CANALS.

687. *Canals* are artificial channels for water, applied to the purpose of inland navigation; for the supply of cities with water; for draining; for irrigation, &c. &c.

688. *Navigable* canals are divided into two classes: 1st. Canals which are on the same level throughout their entire length, as those which are found in low level countries. 2d. Canals which connect two points of different levels, which lie either in the same valley, or on opposite sides of a dividing ridge. This class is found in broken countries, in which it is necessary to divide the entire length of the canal into several level portions, the communication between which is effected by some artificial means. When the points to be connected lie on opposite sides of a dividing ridge, the highest reach, which crosses the ridge, is termed the *summit level*.

689. 1st Class. The surveying and laying out a canal in a level country, are operations of such extreme simplicity as to require no particular notice in this place; since these operations have been fully explained in the subject of Common Roads. The line of the canal should be run in a direct line between the two points to be connected, unless it be found necessary to deflect it at any intermediate points; in which case, the straight portions will be connected by arcs of circles of sufficient curvature to allow the boats used in the navigation to pass each other at the curves, without any diminution of their ordinary rate of speed.

The cross section of this class (Fig. 164) presents usually a

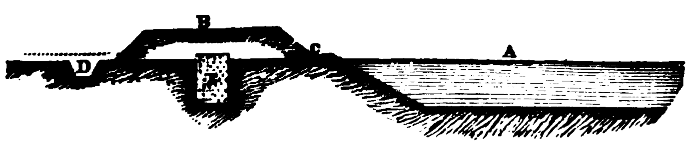


Fig. 164—Cross section of a canal in level cutting.
A, water-way.
B, tow-paths.
C, berms.
D, side-drains.
E, puddling of clay or sand

water-way, or channel of a trapezoidal form, with an embankment on each side, raised above the general level of the country, and formed of the excavation for the water-way. The level, or

surface of the water, is usually above the natural surface, sufficient thickness being given to the embankments to prevent the filtration of the water through them, and to resist its pressure. This arrangement has in its favor the advantage of economy in the labor of excavating and embanking, since the cross section of the cutting may be so calculated as to furnish the necessary earth for the embankment; but it exposes the surrounding country to injury, from accidents happening to the embankments.

The relative dimensions of the parts of the cross section may be generally stated as follows; subject to such modifications as each particular case may seem to demand.

The width of the water-way, at bottom, should be at least twice the width of the boats used in navigating the canal; so that two boats, in passing each other, may, by sheering towards the sides, avoid being brought into contact.

The depth of the water-way should be at least eighteen inches greater than the draft of the boat, to facilitate the motion of the boat, particularly if there are water-plants growing on the bottom.

The side slopes of the water-way, in compact soils, should receive a base at least once-and-a-half the altitude, and proportionally more as the soil is less compact.

The thickness of the embankments, at top, is seldom regulated by the pressure of the water against them, as this, in most cases, is inconsiderable, but to prevent filtration, which, were it to take place, would soon cause their destruction. A thickness from four to six feet, at top, with the additional thickness given by the side slopes at the water surface, will, in most cases, be amply sufficient to prevent filtrations. A pathway for the horses attached to the boats, termed a *tow-path*, which is made on one of the embankments, and a foot-path on the other, which should be wide enough to serve as an occasional tow-path, give a superabundance of strength to the embankments.

The tow-path should be from ten to twelve feet wide, to allow the horses to pass each other with ease; and the foot-path at least six feet wide. The height of the surfaces of these paths, above the water surface, should not be less than two feet, to avoid the wash of the ripple; nor greater than four feet and a half, for the facility of the draft of the horses in towing. The surface of the tow-path should incline slightly outward, both to convey off the surface water in wet weather, and to give a firmer footing to the horses, which naturally draw from the canal.

The side slopes of the embankment vary with the character of the soil: towards the water-way they should seldom be less than two base to one perpendicular; from it, they may, if it be

thought necessary, be less. The interior slope is usually not carried up unbroken from the bottom to the top; but a horizontal space, termed a *bench*, or *berm*, about one or two feet wide, is left, about one foot above the water surface, between the side slope of the water-way and the foot of the embankment above the berm. This space serves to protect the upper part of the interior side slope, and is, in some cases, planted with such shrubbery as grows most luxuriantly in aquatic localities, to protect more efficaciously the banks by the support which its roots give to the soil. The side slopes are better protected by a revêtement of dry stone. Aquatic plants of the bulrush kind have been used, with success, for the same purpose; being planted on the bottom, at the foot of the side slope, they serve to break the ripple, and preserve the slopes from its effects.

The earth of which the embankments are formed should be of a good binding character, and perfectly free from vegetable mould, and all vegetable matter, as the roots of plants, &c. In forming the embankments, the vegetable mould should be carefully removed from the surface on which they are to rest; and they should be carried up in uniform layers, from nine to twelve inches thick, and be well rammed. If the character of the earth, of which the embankments are formed, is such as not to present entire security against filtration, a puddling of clay, or fine sand, two or three feet thick, may be laid in the interior of the mass, penetrating a foot below the natural surface. Sand is useful in preventing filtration caused by the holes made in the embankments near the water surface by insects, moles, rats, &c.

Side drains must be made, on each side, a foot or two from the embankments, to prevent the surface water of the natural surface from injuring the embankments.

690. 2d Class. This class will admit of two subdivisions: 1st, Canals which lie throughout in the same valley; 2d, Canals with a summit level.

Location. In laying out canals, belonging to the first subdivision, the line of direction of the canal should be as direct as practicable between the two points. As the different levels, however, must be laid out on one of the side slopes of the valley, their lines of direction will be nearly the same as the horizontal curved line in which the natural surface of the ground would be intersected by the water surface of the canal produced; the variations in direction from this curve depending on the character of the cuttings and fillings, both as to the advantages which the one may present over the other as regards filtration, and the economy of construction.

With respect to the side slope of the valley along which the canal is to be run, the engineer must be guided in his choice by

the relative expense of construction on the two sides; which will depend on the quantity of cutting and filling, the masonry for the culverts, &c., and the nature of the soil as adapted to holding water. All other things being equal, the side on which the fewest secondary water-courses are found will, generally speaking, offer the greatest advantage as to expense; but, it may happen that the secondary water-courses will be required to feed the canal with water, in which case it will be necessary to lay out the line on the side where they are found most convenient, and in most abundance.

As to the points in which the line of direction should cross the secondary valleys, the engineer will be guided by the same considerations as for any other line of communication; crossing them by following the natural surface, or else by a filling in a right line, as may be most economical.

691. *Cross section.* The side formations of excavations and embankments require peculiar care, particularly the latter, as any crevices, when they are first formed, or which may take place by settling, might prove destructive to the work. In most cases, a stratum of good binding earth, lining the water-way throughout to the thickness of about four feet, if compactly rammed, will be found to offer sufficient security, if the substructure is of a firm character, and not liable to settle. Fine sand has been applied with success to stop the leakage in canals. The sand for this purpose is sprinkled, in small quantities at a time, over the surface of the water, and gradually fills up the outlets in the bottom and sides of the canal. But neither this nor puddling has been found to answer in all cases, particularly where the substructure is formed of fragments of rocks offering large crevices to filtrations, or is of a marly nature. In such cases it has been found necessary to line the water-way throughout with stone, laid in hydraulic mortar. A lining of this character, (Fig. 165,) both at the bottom and sides, formed of fla

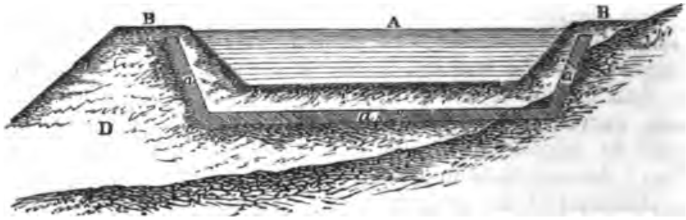


Fig. 165—Cross section of a canal in side cutting lined with masonry.
A, water-way.
B, tow-paths.
D, embankment.
a, masonry lining.

stones, about four inches thick, laid on a bed of hydraulic mortar, one inch thick, and covered by a similar coat of mortar, making the entire thickness of the lining six inches, has been found to answer all the required purposes. This lining should be covered, both at bottom and on the sides, by a layer of good earth, at least three feet thick, to protect it from the shock of the boats striking either of those parts.

The cross section of the canal and its tow-paths in deep cutting (Fig. 166) should be regulated in the same way as in canals

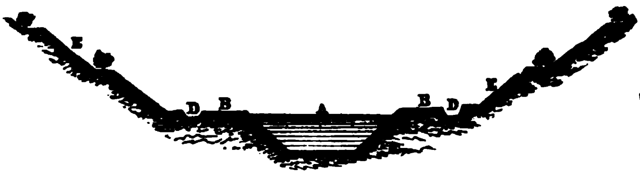


Fig. 166—Cross section of a canal in deep cutting. E, side slopes of cutting.

of the first class; but when the cuttings are of considerable depth, it has been recommended to reduce both to the dimensions strictly necessary for the passage of a single boat. By this reduction there would be some economy in the excavations; but this advantage would, generally, be of too trifling a character to be placed as an offset to the inconveniences resulting to the navigation, particularly where an active trade was to be carried on.

692. *Summit level.* As the water for the supply of the summit level of a canal must be collected from the ground that lies above it, the position selected for the summit level should be at the lowest point practicable of the dividing ridge, between the two branches of the canal. In selecting this point, and the direction of the two branches of the canal, the engineer will be guided by the considerations with regard to the natural features of the surface, which have already been dwelt upon.

693. *Supply of water.* The quantity of water required for canals with a summit level, may be divided into two portions 1st. That which is required for the summit level, and those levels which draw from it their supply. 2d. That which is wanted for the levels below those, and which is furnished from other sources.

The supply of the first portion, which must be collected at the summit level, may be divided into several elements: 1st. The quantity required to fill the summit level, and the levels which draw their supply from it. 2d. The quantity required to supply losses, arising from accidents; as breaches in the banks,

and the emptying of the levels for repairs. 3d. The supplies for losses from surface evaporation, from leakage through the soil, and through the lock gates. 4. The quantity required for the service of the navigation, arising from the passage of the boats from one level to another. Owing to the want of sufficient data, founded on accurate observations, no precise amount can be assigned to these various elements which will serve the engineer as data for rigorous calculation.

The quantity required, in the first place, to fill the summit level and its dependent levels, will depend on their size, an element which can be readily calculated; and upon the quantity which would soak into the soil, which is an element of a very indeterminate character, depending on the nature of the soil in the different levels.

The supplies for accidental losses are of a still less determinate character.

To calculate the supply for losses from surface evaporation, correct observations must be made on the yearly amount of evaporation, and the quantity of rain that falls on the surface; as the loss to be supplied will be the difference between these two quantities.

With regard to the leakage through the soil, it will depend on the greater or less capacity which the soil has for holding water. This element varies not only with the nature of the soil, but also with the shorter or longer time that the canal may have been in use; it having been found to decrease with time, and to be, comparatively, but trifling in old canals. In ordinary soils it may be estimated at about two inches in depth every twenty-four hours, for some time after the canal is first opened. The leakage through the gates will depend on the workmanship of these parts. From experiments by Mr. Fisk, on the *Chesapeake* and *Ohio* canal, the leakage through the locks at the summit level, which are 100 feet long, 15 feet wide, and have a lift of 8 feet, amounts to twelve locks full daily, or about 62 cubic feet per minute. The monthly loss upon the same canal, from evaporation and filtration, is about twice the quantity of water contained in it. From experiments made by Mr. J. B. Jervis, on the *Erie* canal, the total loss, from evaporation, filtration, and leakage through the gates, is about 100 cubic feet per minute, for each mile.

In estimating the quantity of water expended for the service of the navigation, in passing the boats from one level to another, two distinct cases require examination:—1st. Where there is but one lock between two levels, or in other words, when the locks are isolated. 2d. When there are several contiguous locks, or as it is termed, a *flight* of locks between two levels.

694. A *lock* is a small basin just large enough to receive a boat, in which the water is usually confined on the sides by two upright walls of masonry, and at the ends by two gates, which open and shut, both for the purpose of allowing the boat to pass, and to cut off the water of the upper level from the lower, as well as from the lock while the boat is in it. To pass a boat from one level to the other—from the lower to the upper end, for example—the lower gates are opened, and the boat having entered the lock they are shut, and water is drawn from the upper level, by means of valves, to fill the lock and raise the boat, when this operation is finished, the upper gates are opened, and the boat is passed out. To descend from the upper level, the lock is first filled; the upper gates are then opened, and the boat passed in; these gates are next shut, and the water is drawn from the lock, by valves, until the boat is lowered to the lower level, when the lower gates are opened and the boat is passed out.

In the two operations just described, it is evident, that for the passage of a boat, up or down, a quantity of water must be drawn from the upper level to fill the lock to a height which is equal to the difference of level between the surface of the water in the two; this height is termed the *lift* of the lock, and the volume of water required to pass a boat up or down is termed the *prism of lift*. The calculation, therefore, for the quantity of water requisite for the service of the navigation, will be simply that of the number of prisms of lift which each boat will draw from the summit level in passing up or down.

695. Let a boat, on its way up, be supposed to have arrived at the lowest level supplied from the summit level; it will require a prism of lift to ascend the next level above, and so on in succession, until it reaches the summit level, from which one prism of lift must be drawn to enable the boat to enter it. From this it appears that but one prism of lift is drawn from the summit level for the passage of a boat up. Now, in descending on the other side, the boat will require one prism of lift to take it to the next level, and this prism of lift will carry it through all the successive locks, if their lifts are the same. For the entire passage of one boat, then, two prisms of lift must be drawn from the summit level.

This boat will thus leave all the locks full on the side of the ascent, and empty on the side of the descent. Now the next boat may be going in the same, or in an opposite direction, with respect to the first. If it follows the first, it will evidently require two prisms of lift for its entire passage, and will leave the locks in the same state as they were. If it proceeds in an opposite direction, it will require a prism of lift to ascend to the summit

level; but, in descending, it will take advantage of the full lock left by the preceding boat, and will therefore not draw from the summit level for its descent to the next; the same will take place at every level until the last, where it will carry out with it the prism of lift, which was drawn from the summit level for the preceding boat, so that in this case it will draw but one prism of lift from the summit level. If the two boats had met on the summit level, the same would have taken place: therefore, when the boats alternate regularly, each will require but one prism of lift for its entire passage. But as this regularity of alternation cannot be practically carried into effect, an allowance of two prisms of lift must be made for the entire passage of each boat.

In calculating the expenditure for locks in flights, a new element, termed the *prism of draught*, must be taken into account. This prism is the quantity of water required to float the boat in the lock when the prism of lift is drawn off; and is evidently equal in depth to the water in the canal, unless it should be deemed advisable to make it just sufficient for the draught of the boat, by which a small saving of water might be effected.

696. Locks in flights may be considered under two points of view, with regard to the expenditure of water: the first, where both the prism of lift, and that of draught, are drawn off for the passage of a boat; or second, where the prisms of draught are always retained in the locks. The expenditure, of course, will be different for the two cases.

To ascertain what will take place in the two cases, let a case be supposed, in which there is a flight of locks on each side of the summit level, to connect it with the two next lower levels. In the first case, a boat, arriving at the foot of the flight, finds all the locks of the flight empty, except the lowest, which must contain a prism of draught to float the boat in. To raise the boat, then, to the upper level, all the locks of the flight must be filled from the summit level, which will require as many prisms of lift as there are locks, and as many prisms of draught as there are locks less one; or, representing by L the prism of lift, D the prism of draught, and n the number of locks in the flight, the total quantity of water, for the ascent of the boat, will be represented by

$$n\text{L} + (n-1)\text{D}; \quad . \quad . \quad . \quad (1).$$

In descending, on the opposite side, the boat will require a prism of lift and one of draught at the first lock; but to enter the second another prism of draught in addition will be required, and this entire quantity will be sufficient to take it through all the remaining locks of the flight: this quantity will therefore be represented by

$$\text{L} + 2\text{D}; \quad . \quad . \quad . \quad (2).$$

so that for the entire passage of the boat, the total expenditure will be represented by

$$(n + 1)\,\text{L} + (n + 1)\,\text{D}. \quad . \quad (3).$$

The flight, on one side, is thus left full after the passage of the first boat, and on the other side, empty. If a second boat, then, follows directly after the first, the prism of lift must be drawn from the lowest lock to admit the boat, this prism is then supplied from the lock next above, and so on to the summit level; so that but one prism of lift will be drawn off for the ascent of this boat, and it will require one of lift, and two of draught, to carry it down the opposite flight. If, therefore, the total number of boats which follow in this order, including the first, be represented by m, the total expenditure will be represented by

$$(n + 1)\,\text{L} + (n + 1)\,\text{D} + (m - 1)\,2\text{L} + (m - 1)\,2\text{D}. \quad . \quad (4).$$

If the second boat, instead of following the first, arrives in the opposite direction, or alternates with it, the expenditure for its ascent will be represented by the formula (1), and for its descent it will be nothing, since it finds the opposite flight filled, as left by the first boat; but if the locks had been emptied, then the passage of the second boat would have taken place under the same circumstances as that of the first.

It will be unnecessary here to go farther into these calculations for the various cases that may occur, under the different circumstances of passage of the boats or of empty or full flights; the preceding gives the spirit of the method, and will give the means for entering upon a calculation to allow for the loss or gain by the passage of freighted or of empty boats, following any prescribed order of passage. These refinements are, for the most part, more curious than useful; and the engineer should confine himself to making an ample allowance for the most unfavorable cases, both as regards the order of passage and the number of boats.

697. *Feeders and Reservoirs.* Having ascertained, from the preceding considerations, the probable supply which should be collected at the summit level, the engineer will next direct his attention to the sources from which it may be procured. Theoretically considered, all the water that drains from the ground adjacent to the summit level, and above it, might be collected for its supply; but it is found in practice that channels for the conveyance of water must have certain slopes, and that these slopes, moreover, will regulate the supply furnished in a certain time, all other things being equal. In making, however, the survey of the country, from which the water is to be supplied to the summit level, all the ground above it should be examined, leav-

ing the determination of the slopes for after considerations. The survey for this object consists in making an accurate delineation of all the water-courses above the summit level, and in ascertaining the quantity of water which can be furnished by each in a given time. This survey, as well as the measurement of the quantity of water furnished by each stream, which is termed the *gauging*, should be made in the driest season of the year, in order to ascertain the minimum supply.

698. The usual method of collecting the water of the sources, and conveying it to the summit level, is by feeders and reservoirs. The *feeder* is a canal of a small cross section, which is traced on the surface of the ground with a suitable slope, to convey the water either into the reservoir, or direct to the summit level. The dimensions of the cross section, and the longitudinal slope of the feeder, should bear certain relations to each other, in order that it shall deliver a certain supply in a given time. The smaller the slope given to the feeder, the lower will be the points at which it will intersect the sources of supply, and therefore the greater will be the quantity of water which it will receive. This slope, however, has a practical limit, which is laid down at four inches in 1000 yards, or nine thousand base to one altitude; and the greatest slope should not exceed that which would give the current a greater mean velocity than thirteen inches per second, in order that the bed of the feeder may not be injured. Feeders are furnished, like ordinary canals, with contrivances to let off a part, or the whole, of the water in them, in cases of heavy rains, or for making repairs.

But a small proportion of the water collected by the feeders is delivered at the reservoir; the loss from various causes being much greater in them than in canals. From observations made on some of the feeders of canals in France, which have been in use for a long period, it appears that the feeder of the *Briare* canal delivers only about one fourth of the water it gathers from its sources of supply; and that the annual loss of the two feeders of the *Languedoc* canal, amounts to 100 times the quantity of water which they can contain.

699. A *reservoir* is a large pond, or body of water, held in reserve for the necessary supply of the summit level. A reservoir is usually formed by choosing a suitable site in a deep and narrow valley, which lies above the summit level, and erecting a dam of earth, or of masonry, across the outlet of the valley, or at some more suitable point, to confine the water to be collected. The object to be attained, in this case, is to embody the greatest volume of water, and at the same time present the smallest evaporating surface, at the smallest cost for the construction of the dam

It is generally deemed best to have two reservoirs for the supply, one to contain the greater quantity of water, and the other which is termed the *distributing* reservoir, to regulate the supply to the summit level. If, however, the summit level is very capacious, it may be used as the distributing reservoir.

The proportion between the quantity of water that falls upon a given surface, and that which can be collected from it for the supply of a reservoir, varies considerably with the latitude, the season of the year, and the natural features of the locality. The drainage is greatest in high latitudes, and in the winter and spring seasons; with respect to the natural features, a wooded surface with narrow and deep valleys will yield a larger amount than an open flat country.

But few observations have been made on this point by engineers. From some by Mr. J. B. Jervis, in reference to the reservoirs for the *Chenango* canal, in the state of New York, it appears that in that locality about two fifths of the quantity of rain may be collected for the supply of a reservoir. The proportion usually adopted by engineers is one third.

The loss of water from the reservoir by evaporation, filtration, and other causes, will depend upon the nature of the soil, and the exposure of the water surface. From observations made upon some of the old reservoirs in England and France, it appears that the daily loss averages about half an inch in depth.

700. The dams of reservoirs have been variously constructed: in some cases they have been made entirely of earth, (Fig. 167;)

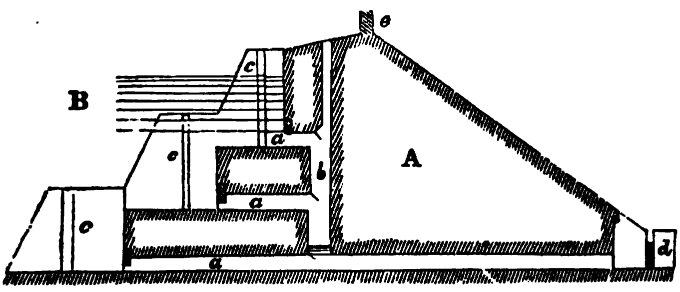


Fig. 167—Represents the section of a dam with three discharging culverts.
A, body of the dam.
B, pond.
a, a, a, culverts, with valves at their inlets, which discharge into the vertical well b.
c, c, c, grooves, in the faces of the side-walls, which form the entrance to the culverts, for stop-plank
d, stop-plank dam across the outlet of the bottom culvert, to dam back the water into the vertical well.
e, parapet wall on top of the dam.

in others, entirely of masonry; and in others, of earth packed in between several parallel stone walls. It is now thought best to

surface of the offset, it should be kept covered with a sheet of water retained by a dam placed across its outlet.

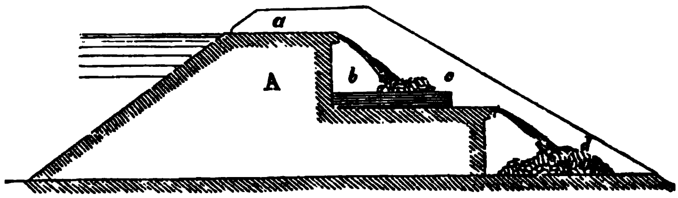


Fig. 169—Represents a section of a waste-weir divided into two falls.
A, body of the dam.
a, top of the waste-weir.
b, pool, formed by a stop-plank dam at c, to break the fall of the water.
d, covering of loose stone to break the fall of the water from the pool above.

703. In extensive reservoirs, in which a large surface is exposed to the action of the winds, waves might be forced over the top of the dam, and subject it to danger; in such cases the precaution should be taken of placing a parapet wall towards the outer edge of the top of the dam, and facing the top throughout with flat stones laid in mortar.

704. *Lift of locks.* From the preceding observations on the expenditure of water for the service of the navigation, it appears that isolated locks are more favorable under this point of view than locks in flights. The engineer is not, however, always left free to select between the two systems; for the form of the natural surface of the ground may compel him to adopt a flight of locks at certain points. As to the comparative expense of the two methods, a flight is in most cases cheaper than the same number of single locks, as there are certain parts of the masonry which can be suppressed. There is also an economy in the suppression of the small gates, which are not needed in flights. It is, however, more difficult to secure the foundations of combined than of single locks from the effects of the water, which forces its way from the upper to the lower level under the locks. Where an active trade is carried on, a double flight is sometimes arranged; one for the ascending, the other for the descending boats. In this case the water which fills one flight may, after the passage of the boat, be partly used for the other, by an arrangement of valves made in the side wall separating the locks.

The lift of locks is a subject of importance, both as regards the consumption of water for the navigation, and the economy of construction. Locks with great lifts, as may be seen from the remarks on the passage of boats, consume more water than those with small lifts. They require also more care in their

construction, to preserve them from accidents, owing to the great pressure of water against their sides. The expense of construction is otherwise in their favor; that is, the expense will increase with the total number of locks, the height to be ascended being the same. The smallest lifts are seldom less than five feet, and the greatest, for ordinary canals, not over twelve; medium lifts of seven or eight feet are considered the best under every point of view. This is a point, however, which cannot be settled arbitrarily, as the nature of the foundations, the materials used, the embankments around the locks, the changes in the direction of the canal, caused by varying the lifts, are so many modifying causes, which should be carefully weighed before adopting a definitive plan.

The lifts of a flight should be the same throughout; but in isolated locks the lifts may vary according to circumstances. If the supply of water from the summit level requires to be economized with care, the lifts of locks which are furnished from it may be less than those lower down.

705. *Levels.* The position and the dimensions of the levels must be mainly determined by the form of the natural surface. Those points are naturally chosen to pass from one level to another, or as the positions for the locks, where there is an abrupt change in the surface.

A level, by a suitable modification of its cross section, can be made as short as may be deemed desirable; there being but one point to be attended to in this, which is, that a boat passing between the two locks, at the ends of the level, will have time to enter either lock before it can ground, on the supposition, that the water drawn off to fill the lower lock, while the boat is traversing the level, will just reduce the depth to the draught of the boat.

706. *Locks.* A lock (Fig. 170) may be divided into three distinct parts:—1st. The part included between the two gates, which is termed the *chamber*. 2d. The part above the upper gates, termed the *fore*, or *head-bay*. 3d. The part below the lower gates, termed the *aft*, or *tail-bay*.

707. The lock chamber must be wide enough to allow an easy ingress and egress to the boats commonly used on the canal; a surplus width of one foot over the width of the boat across the beam is usually deemed sufficient for this purpose. The length of the chamber should be also regulated by that of the boats; it should be such, that when the boat enters the lock from the lower level, the tail-gates may be shut without requiring the boat to unship its rudder.

The plan of the chamber is usually rectangular, as this form is, in every respect, superior to all others. In the cross section

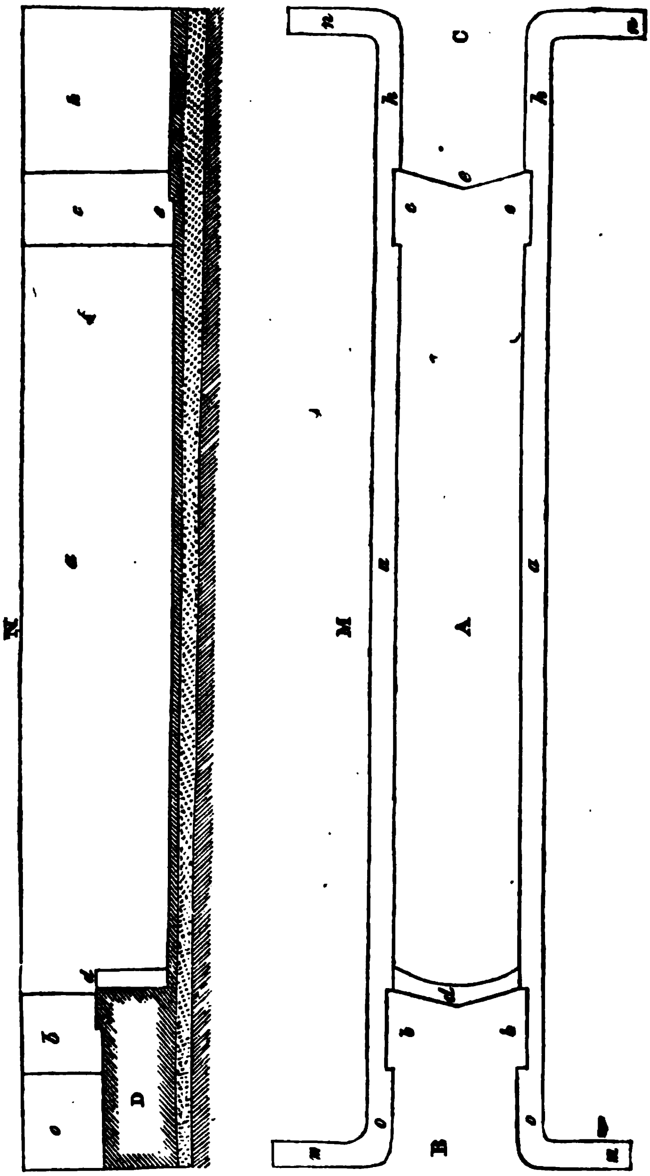


Fig. 178—Represents a plan M, and a section N, through the axis of a single lock laid on a beton foundation.—A, lock-chamber. B, fore-bay. C, tail-bay. *a*, *a*, chamber-walls. *b*, *b*, recesses or chambers in the side walls for upper-gates. *c*, *c*, lower-gate chambers. *d*, *d*, lift wall and upper mitre sill. *e*, *e*, lower mitre sill. *h*, *h*, tail walls. *o*, *o*, head walls. *m*, *m*, upper wing, or return walls. *n*, *n*, lower wing walls. D, body of masonry under the fore-bay

of the chamber, (Fig. 171,) the sides receive generally a slight

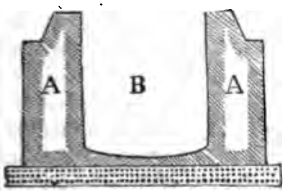


Fig. 171—Represents a section of Fig. 170, through the chamber.
A, A, chamber walls.
B, chamber formed with an inverted-arch bottom

batter; as when so arranged they are found to give greater facility to the passage of the boat than when vertical. The bottom of the chamber is either flat or curved; more water will be required to fill the flat-bottomed chamber than the curved, but it will require less masonry in its construction.

708. The chamber is terminated just within the head gates by a vertical wall, the plan of which is usually curved. As this wall separates the upper from the lower level, it is termed the *lift-wall;* it is usually of the same height as the lift of the levels. The top of the lift-wall is formed of cut stone, the vertical joints of which are normal to the curved face of the wall; this top course projects from six to nine inches above the bottom of the upper level, presenting an angular point, for the bottom of the head-gates, when shut, to rest against. This is termed the *mitre-sill.* Various degrees of opening have been given to the angle between the two branches of the mitre-sill; it is, however, generally so determined, that the perpendicular of the isosceles triangle, formed by the two branches, shall vary between one fifth and one sixth of the base.

As stone mitre-sills are liable to injury from the shock of the gate, they are now usually constructed of timber, (Fig. 172,) by

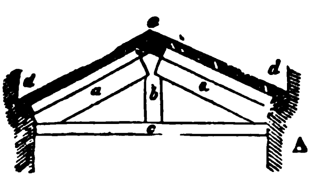


Fig. 172—Represents a plan of a wooden mitre-sill, and a horizontal section of a lock-gate (Fig. 173) closed.
a, a, mitre-sill framed with the pieces *b* and *c,* and firmly fastened to the side walls A, A.
d, section of quoin posts of lock-gate.
e, section of mitre posts.

framing two strong beams with the proper angle for the gate when closed, and securing them firmly upon the top of the lift-wall. It will be well to place the top of the mitre-sill on the lift-wall a little lower than the bottom of the canal, to preserve it from being struck by the keel of the boat on entering, or leaving the lock.

709. The cross section of the chamber walls is usually trapezoidal; the facing receives a slight batter. The chamber walls

are exposed to two opposite efforts; the water in the lock on one side, and the embankment against the wall on the other The pressure of the embankment is the greater as well as the more permanent effort of the two. The dimensions of the wall must be regulated by this pressure. The usual manner of doing this, is to make the wall four feet thick at the water line of the upper level, to secure it against filtration; and then to determine the base of the batter, so that the mass of masonry shall present sufficient stability to counteract the tendency of the pressure. The spread, and other dimensions of the foundations, will be regulated according to the nature of the soil, in the same way as in other structures.

710. The bottom of the chamber, as has been stated, may be either flat or curved. The flat bottom is suitable to very firm soils, which will neither yield to the vertical pressure of the chamber walls, nor admit the water to filter from the upper level under the bottom of the lock. In either of the contrary cases, the bottom should be made with an inverted arch, as this form will oppose greater resistance to the upward pressure of the water under the bottom, and will serve to distribute the weight of the walls over the portion of the foundation under the arch. The thickness of the masonry of the bottom will depend on the width of the chamber, and the nature of the soil. Were the soil a solid rock, no bottoming would be requisite; if it is of soft mud, a very solid bottoming, from three to six feet in thickness, might be requisite.

711. The principal danger to the foundations arises from the water which may filter from the upper to the lower level, under the bottom of the lock. One preventive for this, but not an effectual one, is to drive sheeting piles across the canal at the end of the head-bay; another, which is more expensive, but more certain in its effects, consists in forming a deep trench of two or three feet in width, just under the head-bay, and filling it with beton, which unites at top with the masonry of the head-bay. Similar trenches might be placed under the chamber were it considered necessary.

712. The lift-wall usually receives the same thickness as the chamber walls; but, unless the soil is very firm, it would be more prudent to form a general mass of masonry under the entire head-bay, to a level with the base of the chamber foundations, of which mass the lift-wall should form a part.

713. The head-bay is enclosed between two parallel walls, which form a part of the side walls of the lock. They are terminated by two wing walls, which it will be found most economical to run back at right angles with the side walls. A recess, termed the *gate-chamber*, is made in the wall of the head

bay; the depth of this recess should be sufficient to allow the gate, when open, to fall two or three inches within the facing of the wall, so that it may be out of the way when a boat is passing; the length of the recess should be a few inches more than the width of the gate. That part of the recess where the gate turns on its pivot is termed the *hollow quoin;* it receives what is termed the *heel*, or *quoin-post* of the gate, which is made of a suitable form to fit the hollow quoin. The distance between the hollow quoins and the face of the lift-wall will depend on the pressure against the mitre-sill, and the strength of the stone, eighteen inches will generally be found amply sufficient.

The side walls need not extend more than twelve inches beyond the other end of the gate-chamber. The wing walls may be extended back to the total width of the canal, but it will be more economical to narrow the canal near the lock, and to extend the wing walls only about two feet into the banks, or sides. The dimensions of the side and wing walls of the head-bay are regulated in the same way as the chamber walls.

The bottom of the head-bay is flat, and on the same level with the bottom of the canal; the exterior course of stones at the entrance to the lock should be so jointed as not to work loose.

714. The gate-chambers for the lower gates are made in the chamber walls; and it is to be observed, that the bottom of the chamber, where the gates swing back, should be flat, or be otherwise arranged not to impede the play of the gates.

715. The side walls of the tail-bay are also a part of the general side walls, and their thickness is regulated as in the preceding cases. Their length will depend chiefly on the pressure which the lower gates throw against them when the lock is full; and partly on the space required by the lock-men in opening and shutting gates manœuvred by the balance beam. A calculation must be made for each particular case, to ascertain the most suitable length. The side walls are also terminated by wing walls, similarly arranged to those of the head-bay. The points of junction between the wing and side walls should, in both cases, either be curved, or the stones at the angles be rounded off. One or two perpendicular grooves are sometimes made in the side walls of the tail-bay, to receive stop-planks, when a temporary dam is needed, to shut off the water of the lower level from the chamber, in case of repairs, &c. Similar arrangements might be made at the head-bay, but they are not indispensable in either case.

The strain on the walls at the hollow quoins is greater than at any other points, owing to the pressure at those points from the gates, when they are shut, and to the action of the gates when in motion; to counteract this, and strengthen the walls, but

tresses should be placed at the back of the walls in the most favorable position behind the quoins to subserve the object in view.

The bottom of the tail-bay is arranged, in all respects, like that of the head-bay.

716. The top of the side walls of the lock may be from one to two feet above the general level of the water in the upper reach; the top course of the masonry being of heavy large blocks of cut stone, although this kind of coping is not indispensable, as smaller masses have been found to suit the same purpose, but they are less durable. As to the masonry of the lock, in general, it is only necessary to observe, that those parts alone need be of cut stone where there is great wear and tear from any cause, as at the angles generally; or where an accurate finish is indispensable, as at the hollow quoins. The other parts may be of brick, rubble, beton, &c., but every part should be laid in the best hydraulic mortar.

717. The filling and emptying the lock chamber have given rise to various discussions and experiments, all of which have been reduced to the comparative advantages of letting the water in and off by valves made in the gates themselves, or by culverts in the side walls, which are opened and shut by valves. When the water is let in through valves in the gates, its effects on the sides and bottom of the chamber are found to be very injurious, particularly in high lift-walls; besides the inconvenience resulting from the agitation of the boat in the lock. To obviate this, in some degree, it has been proposed to give the lift-wall the form of an inclined curved surface, along which the water might descend without producing a shock on the bottom.

718. The side culverts are small arched conduits, of a circular, or an elliptical cross section, which are made in the mass of masonry of the side-walls, to convey the water from the upper level to the chamber. These culverts, in some cases, run the entire length of the side walls, on a level with the bottom of the chamber, from the lift-wall to the end of the tail-wall, and have several outlets leading to the chamber. They are arranged with two valves, one to close the mouth of the culvert, at the upper level, the other to close the outlet from the chamber, to the lower level. This is, perhaps, one of the best arrangements for side culverts. They all present the same difficulty in making repairs when out of order, and they are moreover very subject to accidents. They are therefore on these accounts inferior to valves in the gates.

719. It has also been proposed, to avoid the inconveniences of culverts, and the disadvantages of lift-walls, by suppressing the latter, and gradually increasing the depth of the upper level,

to the bottom of the chamber. This method presents a saving in the mass of masonry, but the gates will cost more, as the head and tail gates must be of the same height. It would entirely remove the objection to valves in the gates, as the current through them, in this case, would not be sufficiently strong to injure the masonry.

720. The bottom of the canal below the lock should be protected by what is termed an *apron*, which is a covering of plank laid on a grillage, or else one of brush-wood and dry stone. The sides should also be faced with timber or dry stone. The length of this facing will depend on the strength of the current; generally not more than from fifteen to thirty feet from the lock will require it. The entrance to the head-bay is, in some cases, similarly protected, but this is unnecessary, as the current has but a very slight effect at that point.

721. Locks constructed of timber and dry stone, termed *composite-locks*, are to be met with on several of the canals of the United States. The side walls are formed of dry stone carefully laid; the sides of the chamber being faced with plank nailed to horizontal and upright timbers, which are firmly secured to the dry stone walls. The walls rest upon a platform laid upon heavy beams placed transversely to the axis of the lock. The bottom of the chamber usually receives a double thickness of plank The quoin-posts and mitre-sills are formed of heavy beams.

722. *Lock Gates.* A lock gate (Fig. 173) is composed of two

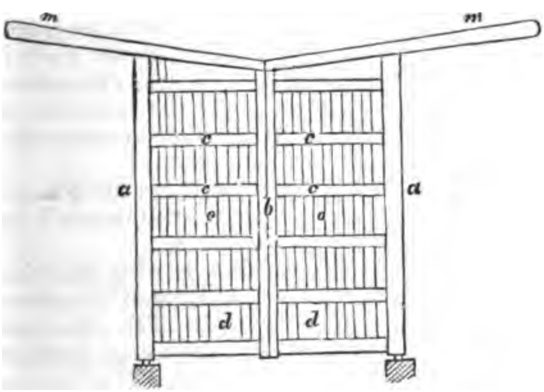


Fig. 173—Represents the elevation of a lock-gate closed.
a, *a*, quoin-posts.
b, mitre-posts.
c, *c*, cross pieces framed into *a* and *b* and firmly connected with them by wrought iron plates.
o, plank or sheathing of the gate.
d, valve.
m, *m*, balance-beam.

leaves, each leaf consisting of a solid frame-work covered on the side towards the water with thick plank made water-tight. The frame usually consists of two uprights, of several horizontal cross pieces let into the uprights, and sometimes a diagonal piece, or brace, intended to keep the frame of an invariable

form, is added. The upright, around which the leaf turns, termed the *quoin* or *heel-post*, is rounded off on the back to fit in the hollow quoin; it is made slightly eccentric with it, so that it may turn easily without rubbing against the quoin; its lower end rests on an iron *gudgeon*, to which it is fitted by a corresponding indentation in an iron *socket* on the end; the upper extremity is secured to the side walls by an iron *collar*, within which the post turns. The collar is so arranged that it can be easily fastened to, or loosened from two iron bars, termed *anchor-irons*, which are firmly attached by bolts, or a lead sealing, to the top course of the walls. One of the anchor-irons is placed in a line with the leaf when shut, the other in a line with it when open, to resist most effectually the strain in those two positions of the gate. The opposite upright, termed the *mitre-post*, has one edge bevelled off, to fit against the mitre-post of the other leaf of the gate.

723. A long heavy beam, termed a *balance beam*, from its partially balancing the weight of the leaf, rests on the quoin post, to which it is secured, and is mortised with the mitre post. The balance beam should be about four feet above the top of the lock, to be readily manœuvred; its principal use being to open and shut the leaf.

724. The top cross piece of the gate should be about on a level with the top of the lock; the bottom cross piece should swing clear of the bottom of the lock. The position of the intermediate cross pieces may be made to depend on their dimensions: if they are of the same dimensions, they should be placed nearer together at the bottom, as the pressure of the water is there greatest; but, by making them of unequal dimensions, they may be placed at equal distances apart; this, however, is not of much importance except for large gates, and considerable depths of water.

The plank may be arranged either parallel to the uprights, or parallel to the diagonal brace; in the latter position they will act with the brace to preserve the form of the frame.

725. A wide board supported on brackets, is often affixed to the gates, both for the manœuvre of the machinery of the valves, and to serve as a foot bridge across the lock. The valves are small gates which are arranged to close the openings made in the gates for letting in, or drawing off the water. They are arranged to slide up and down in grooves, by the aid of a rack and pinion, or a square screw; or they may be made to open or shut by turning on a vertical axis, in which case they are termed *paddle gates*. The openings in the upper gates are made between the two lowest cross pieces. In the lower gates the openings are placed just below the surface of the water in the reach. The

size of the opening will depend on the time in which it is required to fill the lock.

726. *Accessory Works.* Under this head are classed those constructions which are not a part of the canal proper, although generally found necessary on all canals: as the culverts for conveying off the water courses which intersect the line of the canal; the inlets of feeders for the supply of water; aqueduct bridges, &c. &c.

727. *Culverts.* The disposition to be made of water courses intersecting the line of the canal will depend on their size, the character of their current, and the relative positions of the canal and stream.

Small brooks which lie lower than the canal may be conveyed under it through an ordinary culvert. If the level of the canal and brook is nearly the same, it will then be necessary to make the culvert in the shape of an inverted syphon, and it is therefore termed a *broken-back* culvert. If the water of the brook is generally limpid, and its current gentle, it may, in the last case, be received into the canal. The communication of the brook, or feeder, with the canal, should be so arranged that the water may be shut off, or let in at pleasure, in any quantity desired. For this purpose a cut is made through the side of the canal, and the sides and bottom of the cut are faced with masonry laid in hydraulic mortar. A sliding gate, fitted into two grooves made in the side walls, is manœuvred by a rack and pinion, so as to regulate the quantity of water to be let in. The water of the feeder, or brook, should first be received in a basin, or reservoir, near the canal, where it may deposite its sediment before it is drawn off. In cases where the line of the canal is crossed by a torrent, which brings down a large quantity of sand, pebbles, &c., it may be necessary to make a permanent structure over the canal, forming a channel for the torrent; but if the discharge of the torrent is only periodical, a moveable channel may be arranged, for the same purpose, by constructing a boat with a deck and sides to form the water-way of the torrent. The boat is kept in a recess in the canal near the point where it is used, and is floated to its position, and sunk when wanted.

728. *Aqueducts, &c.* When the line of the canal is intersected by a wide water-course, the communication between the two shores must be effected either by a canal aqueduct bridge, or by the boats descending from the canal into the stream. As the construction of aqueduct bridges has already been considered nothing farther on this point need here be added. The expedient of crossing the stream by the boats may be attended with many grave inconveniences in water courses liable to freshets or to considerable variations of level at different seasons. In

these cases locks must be so arranged on each side, where the canal enters the stream, that boats may pass from the one to the other under all circumstances of difference of level between the two. The locks and the portions of the canal which join the stream must be secured against damage from freshets by suitable embankments; and, when the summer water of the stream is so low that the navigation would be impeded, a dam across the stream will be requisite to secure an adequate depth of water during this epoch.

729. *Canal Bridges.* Bridges for roads over a canal, termed *canal-bridges*, are constructed like other structures of the same kind. In planning them the engineer should endeavor to give sufficient height to the bridge to prevent those accidents, of but too frequent occurrence, from persons standing upright on the deck of the passage-boat while passing under a bridge.

730. *Waste-Wier.* Waste-wiers must be made along the levels to let off the surplus water. The best position for them is at points where they can discharge into natural water courses. The best arrangement for a waste-wier is to make a cut through the side of the canal to a level with the bottom of it, so that, in case of necessity, the waste-wier may also serve for draining the level. The sides and bottom of the cut must be faced with masonry, and have grooves left in them to receive stop-plank, or a sliding gate, over which the surplus water is allowed to flow, under the usual circumstances, but which can be removed, if it be found necessary, either to let off a larger amount of water, or to drain the level completely.

731. *Temporary Dams.* In long levels an accident happening at any one point might cause serious injury to the navigation, besides a great loss of water. To prevent this, in some measure, the width of the canal may be diminished, at several points of a long level, to the width of a lock, and the sides, at these points, may be faced with masonry, arranged with grooves and stop-planks, to form a temporary dam for shutting off the water on either side.

732. *Tide, or Guard Lock.* The point at which a canal enters a river requires to be selected with judgment. Generally speaking, a bar will be found in the principal water course at, or below, the points where it receives its affluents. When the canal, therefore, follows the valley of an affluent, its outlet should be placed below the bar, to render its navigation permanently secure from obstruction. A large basin is usually formed at the outlet, for the convenience of commerce; and the entrance from this basin to the canal, or from the river to the basin, is effected by means of a lock with double gates, so arranged that a boat can be passed either way, according as the level in the one

is higher or lower than that in the other. A lock so arranged is termed a *tide*, or *guard lock*, from its uses. The position of the tail of this lock is not indifferent in all cases where it forms the outlet to the river; for were the tail placed up stream, it would be more difficult to pass in or out, than if it were down stream.

733. The general dimensions of canals and their locks in this country and in Europe, with occasional exceptions, do not differ in any considerable degree.

English Canals. Two classes of canals are to be met with in England, differing materially in their dimensions. The following are the usual dimensions of the cross section of the largest size, and those of their locks :—

Width of section at the water level, from	36 to 40 feet.
Width at bottom, ...	24 "
Depth, ...	5 "
Length of lock between mitre-sills,	75 to 85 "
Width of chamber, ...	15 "

The Caledonian canal, in Scotland, which connects Loch-Eil on the Western sea with Murray Firth on the Eastern, is remarkable for its size, which will admit of the passage of frigates of the second class. The following are the principal dimensions of the cross section of the canal and its locks :—

Width of canal at the water level, .	110 feet.
Width at bottom, ...	50 "
Depth of water, ...	20 "
Width of berm, ...	6 "
Length of lock between mitre-sills, .	180 "
Width of chamber at top, ...	40 "
Lift of lock, ...	8 "

The side walls of the locks are built with a curved batter; they are of the uniform thickness of 6 feet, and are strengthened by counterforts, placed about 15 feet apart, which are 4 feet wide and of the same thickness. The bottom of the chamber is formed with an inverted arch.

French Canals. In France the following uniform system has been established for the dimensions of canals and their locks :—

Width of canal at water level, . .	52 feet.
Width at bottom, ...	33 to 36 "
Depth of water, ...	5 "
Length of lock between mitre-sills, .	115 "
Width of lock, ...	17 "

The boats adapted to these dimensions are from 105 to 108 feet long, 16½ feet across the beam, and have a draught of 4 feet.

The English and French canals usually have but one tow-path which is from 9 to 12 feet wide, and about 2 feet above the water level. The side of the tow-path embankment next to the water-way is usually faced either with dry stone, masonry, or planks retained by short piles.

Canals of the United States and Canada. The original dimensions of the New-York Erie canal and its locks, have been generally adopted for similar works subsequently constructed in most of the other states. The dimensions of this canal and its locks are as follows:—

Width of canal at top,	40 feet.
Width at bottom,	28 "
Depth of water,	4 "
Width of tow-path,	9 to 12 "
Length of locks between mitre-sills,	90 "
Width of locks,	15 "

For the enlargement of the Erie canal, the following dimensions have been adopted:—

Width of canal at top,	70 feet.
Width at bottom,	42 "
Depth of water,	7 "
Width of tow-path,	14 "
Length of locks between mitre-sills,	110 "
Width of lock at top,	18.8 "
Width of lock at bottom,	14.6 "
Lift of locks,	8 "

Between the double locks a culvert is placed, which allows the water to flow from the level above the lock to the one below, when there is a surplus of water in the former.

A well, or pit, is left between the lift-wall of the lock and the cross wall which retains the earth at the head of the lock to the level of the bottom of the canal. This pit, receiving the deposite of sand and gravel brought down by the current, prevents it from obstructing the play of the gates.

On the Chesapeake and Ohio canal, the cross section of the canal below Harper's Ferry has received the following dimensions:—

Width of canal at top,	60 feet.
Width at bottom,	42 "
Depth of water,	6 "
Length of locks between mitre-sills,	90 "
Width of locks,	15 "

The following dimensions have been adopted on the James river canal, in Virginia:—

Width of canal at top, ...	50 feet.
Width at bottom, ...	30 "
Depth of water, ...	5 "
Length of locks, ...	100 "
Width of locks, ...	15 "

The Rideau canal, which connects Lake Ontario with the River Ottawa, is arranged for steam navigation. A considerable portion of this line consists of slack-water navigation, formed by connecting the natural water-courses between the outlets of the canal. The length of the locks on this canal is 134 feet between the mitre-sills, and their width 33 feet.

The Welland canal, between lakes Erie and Ontario, as originally constructed, received the following dimensions:—

Width of canal at top, ...	56 feet.
Width at bottom, ...	24 "
Depth of water, ...	8 "
Length of locks betwen mitre-sills, .	110 "
Width of locks, ...	22 "

The canals and locks made to avoid the dangerous rapids of the St. Lawrence are in all respects among the largest in the world. The following are the dimensions of the portion of the canal and the locks between Long Sault and Cornwall:—

Width of canal at top, ...	132 feet.
Width at bottom, ...	100 "
Depth of water, ...	8 "
Width of tow-path, ...	12 "
Length of locks between mitre-sills, .	200 "
Width of locks at top, ...	56.6 "
Width of locks at bottom, ...	43 "

A berm of ·5 feet is left on each side between the water way and the foot of the interior slope of the tow-path. The height of the tow-path is 6 feet above the berm. By increasing the depth of water in the canal to 10 feet, the water line at top can be increased to 150 feet.

RIVERS.

734. *Natural features of Rivers.* All rivers present the same natural features and phenomena, which are more or less strongly marked and diversified by the character of the region through which they flow. Taking their rise in the highlands, and gradually descending thence to some lake, or sea, their beds are modified by the nature of the soil of the valleys in which they lie, and the velocities of their currents are affected by the same causes. Near their sources, their beds are usually rocky, irregular, narrow, and steep, and their currents are rapid. Approaching their outlets, the beds become wider and more regular, the declivity less, and the current more gentle and uniform. In the upper portions of the beds, their direction is more direct, and the obstructions met with are usually of a permanent character, arising from the inequalities of the bottom. In the lower portions, the beds assume a more tortuous course, winding through their valleys, and forming those abrupt bends, termed *elbows*, which seem subject to no fixed laws; and here are found those obstructions, of a more changeable character, termed *bars*, which are caused by deposites in the bed, arising from the wear of the banks by the current.

735. The relations which are found to exist between the cross section of a river, its longitudinal slope, the nature of its bed, and its volume of water, are termed the *regimen* of the river. When these relations remain permanently invariable, or change insensibly with time, the river is said to have a *fixed regimen.*

736. Most rivers acquire in time a fixed regimen, although periodically, and sometimes accidentally, subject to changes from freshets caused by the melting of snow, and heavy falls of rain. These variations in the volume of water thrown into the bed, cause corresponding changes in the velocity of the current, and in the form and dimensions of the bed. These changes will depend on the character of the soil, and the width of the valley. In narrow valleys, where the banks do not readily yield to the action of the current, the effects of any variation of velocity will only be temporarily to deepen the bed. In wide valleys, where the soil of the banks is more easily worn by the current than the bottom, any increase in the volume of water will widen the bed; and if one bank yields more than the other, an elbow will be formed, and the position of the bed will be gradually shifted towards the concave side of the elbow

737. The formation of elbows occasions also variations in the depth and velocity of the water. The greatest depth is found at the concave side. At the straight portions which connect two elbows, the depth is found to decrease, and the velocity of the current to increase. The bottom of the bed thus presents a series of undulations, forming shallows and deep pools, with rapid and gentle currents.

738. Bars are formed at those points, where from any cause the velocity of the current receives a sudden check. The particles suspended in the water, or borne along over the bottom of the bed by the current, are deposited at these points, and continue to accumulate, until, by the gradual filling of the bed, the water acquires sufficient velocity to bear farther on the particles that reach the bar, when the river at this point acquires and retains a fixed regimen, until disturbed by some new cause.

739. The points at which these changes of velocity usually take place, and near which bars are found, are at the junction of a river with its affluents, at those points where the bed of the river receives a considerable increase in width, at the straight portions of the bed between elbows, and at the outlet of the river to the sea. The character of the bars will depend upon that of the soil of the banks, and the velocity of the current. Generally speaking, the bars in the upper portions of the bed will be composed of particles which are larger than those by which they are formed lower down. These accumulations at the mouths of large rivers form in time extensive shallows, and great obstructions to the discharge of the water during the seasons of freshets. The river then, not finding a sufficient outlet by the ordinary channel, excavates for itself others through the most yielding parts of the deposites. In this manner are formed those features which characterize the outlets of many large rivers, and which are termed *delta*, after the name given to the peculiar shape of the outlets of the Nile.

740. *River Improvements*. There is no subject that falls within the province of the engineer's art, that presents greater difficulties and more uncertain issues than the improvement of rivers. Ever subject to important changes in their regimen, as the regions by which they are fed are cleared of their forests and brought under cultivation, one century sees them deep, flowing with an equable current, and liable only to a gradual increase in volume during the seasons of freshets; while the next finds their beds a prey to sudden and great freshets, which leave them, after their violent passage, obstructed by ever shifting bars and elbows. Besides these revolutions brought about in the course of years, every obstruction temporarily placed in the way of the current every attempt to guard one point from its action by any artificial

means, inevitably produces some corresponding change at another, which can seldom be foreseen, and for which the remedy applied may prove but a new cause of harm. Thus, a bar removed from one point is found gradually to form lower down; one bank protected from the current's force transfers its action to the opposite one, on any increase of volume from freshets, widening the bed, and frequently giving a new direction to the channel. Owing to these ever varying causes of change, the best weighed plans of river improvement sometimes result in complete failure.

741. In forming a plan for a river improvement, the principal objects to be considered by the engineer, are, 1st, The means to be taken to protect the banks from the action of the current. 2d, Those to prevent inundations of the surrounding country. 3d, The removal of bars, elbows, and other natural obstructions to navigation. 4th, The means to be resorted to for obtaining a suitable depth of water for boats, of a proper tonnage, for the trade on the river.

742. *Means for protecting the banks.* To protect the banks, either the velocity of the current in-shore must be decreased so as to lessen its action on the soil; or else a facing of some material sufficiently durable to resist its action must be employed. The former method may be used when the banks are low and have a gentle declivity. The simplest plan for this purpose consists either in planting such shrubbery on the declivity as will thrive near water; or by driving down short pickets and interlacing them with twigs, forming a kind of wicker-work. These constructions break the force of the current, and diminish its velocity near the shore, and thus cause the water to deposite its finer particles, which gradually fill out and strengthen the banks. If the banks are high, and are subject to cave in from the action of the current on their base, they may be either cut down to a gentle declivity, as in the last case; or else they may receive a slope of nearly 45°, and be faced with dry stone, care being taken to secure the base by blocks of loose stone, or by a facing of brush and stone laid in alternate layers.

743. *Measures against inundations.* At the points in the course of a river where inundations are to be apprehended, the water-way, if practicable, should be increased; all obstructions to the free discharge of the water below the point should be removed; and dikes of earth, usually termed *levées*, should be raised on each side of the river. By increasing the water-way a temporary improvement only will be effected; for, except in the season of freshets, the velocity of the current at this point will be so much decreased as to form deposites, which, at some future day, may prove a cause of damage. In confining the water between levées, two methods have been tried; the one consists in

leaving a water-way strictly necessary for the discharge of freshets; the other in giving the stream a wide bed. The Po in Italy and the Mississippi present examples of the former method; the effect of which in both cases has been to raise the bed of the stream so much that in many parts the water is habitually above the natural surface of the country, leaving it exposed to serious inundations should the levées give way. The other method has been tried on the Loire in France, and observation has proved that the general level of the bed has not sensibly risen for a long series of years; but it has been found that the bars, which are formed after each freshet, are shifted constantly by the next, so that when the waters have subsided to their ordinary state, the navigation is extremely intricate from this cause. Other means have been tried, such as opening new channels at the exposed points, or building dams above them to keep the water back; but they have all been found to afford only a temporary relief.

744. *Elbows.* The constant wear of the bank, and shifting of the channel towards the concave side of elbows, have led to various plans for removing the inconveniences which they present to navigation. The method which has been most generally tried for this purpose consists in building out dikes, termed *wing-dams*, from the concave side into the stream, placing them either at right angles to the thread of the current, or obliquely down stream, so as to deflect the current towards the opposite shore.

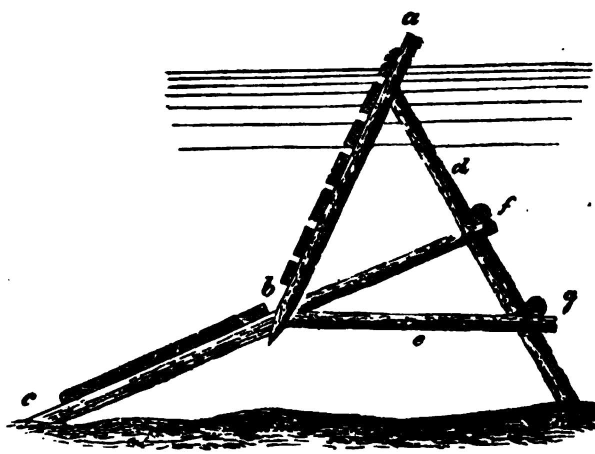


Fig. 174—Represents a section of the timber wing-dams on the Po, formed of plank nailed on the inclined pieces of the ribs.
ab and *bc*, inclined faces of the dam, the first making an angle of 63°, and the second of 23° with the horizon.
d and *e*, pieces of the rib.
f and *g*, horizontal pieces connecting the ribs.

Wing-dams are usually constructed either of blocks of stone of crib-work formed of heavy timbers filled in with broken stone or of alternate layers of gravel and fascines. Within a few years back, wing-dams, consisting simply of a series of vertical frames, or ribs, (Fig. 174,) strongly connected together, and covered on the up-stream side by thick plank, which present a broken inclined plane to the current, the lower part of which is less steep than the upper, have been used upon the Po, with, it is stated, complete success, for arresting the wear of a bank by the current. These dams are placed at some distance above the point to be protected, and their plan is slightly convex on the up-stream side.

Wing-dams of the ordinary form and construction are now regarded, from the experience of a long series of years on the Rhine, and some other rivers in Europe, as little serviceable, if not positively hurtful, as a river improvement, and the abandonment of their use has been strongly urged by engineers in France.

The action of the current against the side of the dam causes whirls and counter-currents, which are found to undermine the base of the dam, and the bank adjacent to it. Shallows and bars are formed in the bed of the stream, near the dam, by the débris borne along by the current after it passes the dam, giving very frequently a more tortuous course to the channel than it had naturally assumed in the elbow. The best method yet found of arresting the progress of an elbow is to protect the concave bank by a facing of dry stone, formed by throwing in loose blocks of stone along the foot of the bank, and giving them the slope they naturally assume when thus thrown in.

745. Elbows upon most rivers finally reach that state of development in which the wear upon the concave side, from the action of the current, will be entirely suspended, and the regimen of the river at these points will remain stable. This state will depend upon the nature of the soil of the banks and bed, and the character of the freshets. From observations made upon the Rhine, it is stated that elbows, with a radius of curvature of nearly 3000 yards, preserve a fixed regimen; and that the banks of those which have a radius of about 1500 yards are seldom injured if properly faced.

746. Attempts have, in some cases, been made to shorten and straighten the course of a river, by cutting across the tongue of land that forms the convex bank of the elbow, and turning the water into a new channel. It has generally been found that the stream in time forms for itself a new bed of nearly the same character as it originally had

747. *Bars.* To obtain a sufficient depth of water over bars, the deposite must either be scooped up by machinery, and be

conveyed away, or be removed by giving an increased velocity to the current. When the latter plan is preferred, an artificial channel is formed, by contracting the natural way, confining it between two low dikes, which should rise only a little above the ordinary level of low water, so that a sufficient outlet may be left for the water during the season of freshets, by allowing it to flow over the dams.

If the river separates into several channels at the bar, dams should be built across all except the main channel, so that by throwing the whole of the water into it the effects of the current may be greater upon the bed.

The longitudinal dikes, between which the main channel is confined, should be placed as nearly as practicable in the direction which the channel has naturally assumed. If it be deemed advisable to change the position of the channel, it should be shifted to that side of the bed which will yield most readily to the action of the current.

748. In situations where large reservoirs can be formed near the bar, the water from them may be used for removing it. For this purpose an outlet is made from the reservoir, in the direction of the bar, which is closed by a gate that turns upon a vertical axis, and is so arranged that it can be suddenly thrown open to let off the water. The chase of water formed in this way sweeping over the bar will prevent the accumulation of deposites upon it. This plan is frequently resorted to in Europe for the removal of deposites that accumulate at the mouth of harbors in those localities where, from the height to which the tide rises, a great head of water can be obtained in the reservoirs.

749. In the improvement of the mouths of rivers which empty into the sea through several channels, no obstruction should be placed to the free ingress of the tides through all the channels. If the main channel is subject to obstructions from deposites, dams should be built across the secondary channels, which may be so arranged with cuts through them closed by gates, that the flood-tide will meet with no obstruction from the gates, while the ebb-tide, causing the gates to close, will be forced to recede through the main channel, which, in this way, will be daily scoured, and freed from deposites by the ebb current. The same object may be effected by building dams without inlets across the secondary channels, giving them such a height that at a certain stage of the flood-tide, the water will flow over them, and fill the channels above the dams. The portion of water thus dammed in will be forced through the main channel at the ebb.

750. When the bed is obstructed by rocks, it may be deepened by blasting the rocks, and removing the fragments with the assistance of the diving-bell, and other machinery.

751. In some of our rivers, obstructions of a very dangerous character to boats are met with, in the trunks of large trees which are imbedded in the bottom at one end, while the other is near the surface; they are termed *snags* and *sawyers* by the boatmen. These obstructions have been very successfully removed, within late years, by means of machinery, and by propelling two heavy boats, moved by steam, which are connected by a strong beam across their bows, so that the beam will strike the snag, and either break it off near the bottom, or uproot it Other obstructions, termed *rafts*, formed by the accumulation of drift wood at points of a river's course, are also found in some of our western rivers. These are also in process of removal, by cutting through them by various means which have been found successful.

752. *Slack-Water Navigation.* When the general depth of water in a river is insufficient for the draught of boats of the most suitable size for the trade on it, an improvement, termed *slack-water*, or *lock and dam navigation*, is resorted to. This consists in dividing the course into several suitable ponds, by forming dams to keep the water in the pond at a constant head; and by passing from one pond to another by locks at the ends of the dams.

753. The position of the dams, and the number requisite, will depend upon the locality. In streams subject to heavy freshets, it will generally be advisable to place the dams at the widest parts of the bed, to obtain the greatest outlet for the water over the dam. The dams may be built either in a straight line between the banks and perpendicular to the thread of the current, or they may be in a straight line oblique to the current, or their plan may be convex, the convex surface being up stream, or it may be a broken line presenting an angle up stream. The three last forms offer a greater outlet than the first to the water that flows over the dam, but are more liable to cause injury to the bed below the stream, from the oblique direction which the current may receive, arising from the form of the dam at top.

754. The cross section of a dam is usually trapezoidal, the face up-stream being inclined, and the one down-stream either vertical or inclined. When the down stream face is vertical, the velocity of the water which flows over the dam is destroyed by the shock against the water of the pond below the dam, but whirls are formed which are more destructive to the bed than would be the action of the current upon it along the inclined face of a dam. In all cases the sides and bed of the stream, for some distance below the dam, should be protected from the action of the current by a facing of dry stone, timber, or any other construction of sufficient durability for the object in view.

755. The dams should receive a sufficient height only to maintain the requisite depth of water in the ponds for the purposes of navigation. Any material at hand, offering sufficient durability against the action of the water, may be resorted to in their construction. Dams of alternate layers of brush and gravel, with a facing of plank, fascines, or dry stone, answer very well in gentle currents. If the dam is exposed to heavy freshets, to blocks of ice, and other heavy floating bodies, as drift-wood, it would be more prudent to form it of dry stone entirely, or of crib-work filled with stone; or, if the last material cannot be obtained, of a solid crib-work alone. If the dam is to be made water-tight, sand and gravel in sufficient quantity may be thrown in against it in the upper pond. The points where the dam joins the banks, which are termed the *roots* of the dam, require particular attention to prevent the water from filtering around them. The ordinary precaution for this is to build the dam some distance back into the banks.

756. The safest means of communication between the ponds is by an ordinary lock. It should be placed at one extremity of the dam, an excavation in the bank being made for it, to secure it from damage by floating bodies brought down by the current. The sides of the lock and a portion of the dam near it should be raised sufficiently high to prevent them from being overflowed by the heaviest freshets. When the height to which the freshets rise is great, the leaves of the head gates should be formed of two parts, as a single leaf would, from its size, be too unwieldy; the lower portion being of a suitable height for the ordinary manœuvres of the lock; the upper, being used only during the freshets, are so arranged that their bottom cross pieces shall rest, when the gates are closed, against the top of the lower portions. An arrangement somewhat similar to this may be made for the tail gates, when the lifts of the locks are great, to avoid the difficulty of manœuvring very high gates, by permanently closing the upper part of the entrance to the lock at the tail gates, either by a wall built between the side walls, or by a permanent framework, below which a sufficient height is left for the boats to pass.

757. A common, but unsafe method of passing from one pond to another, is that which is termed *flashing;* it consists of a sluice in the dam, which is opened and closed by means of a gate revolving on a vertical axis, which is so arranged that it can be manœuvred with ease. One plan for this purpose is to divide the gate into two unequal parts by an axis, and to place a valve of such dimensions in the greater, that when opened the surface against which the water presses shall be less than that of the smaller part. The play of the gate is thus rendered very simple; when the valve is shut, the pressure of water on the larger sur-

face closes it against the sides of the sluice; when the valve is opened, the gate swings round and takes a position in the direction of the current. Various other plans for flashing, on similar principles, are to be met with.

758. When the obstruction in a river cannot be overcome by any of the preceding means, as for example in those considerable descents in the bed known as rapids, where the water acquires a velocity so great that a boat can neither ascend nor descend with safety, resort must be had to a canal for the purpose of uniting its navigable parts above and below the obstruction.

The general direction of the canal will be parallel to the bed of the river. In some cases it may occupy a part of the bed by forming a dike in the bed parallel to the bank, and sufficiently far from it to give the requisite width to the canal. Whatever position the canal may occupy, every precaution should be taken to secure it from damage by freshets.

759. A lock will usually be necessary at each extremity of the canal where it joins the river. The positions for the extreme locks should be carefully chosen, so that the boats can at all times enter them with ease and safety. The locks should be secured by guard gates and other suitable means from freshets; and if they are liable to be obstructed by deposites, arrangements should be made for their removal either by a chase of water, or by machinery.

If the river should not present a sufficient depth of water at all seasons for entering the canal from it, a dam will be required at some point near the lock to obtain the depth requisite.

It may be advisable in some cases, instead of placing the extreme locks at the outlets of the canal to the river, to form a capacious basin at each extremity of the canal between the lock and river, where the boats can lie in safety. The outlets from the basins to the rivers may either be left open at all times, or else guard gates may be placed at them to shut off the water during freshets.

SEACOAST IMPROVEMENTS.

760. The following subdivisions may be made of the works belonging to this class of improvements. 1st. Artificial Roadsteads. 2d. The works required for natural and artificial Harbors. 3d. The works for the protection of the seacoast against the action of the sea.

761. Before adopting any definitive plan for the improvement of the seacoast at any point, the action of the tides, currents, and waves at that point must be ascertained.

762. The theory of tides is well understood; their rise and duration, caused by the attraction of the sun and moon, are also dependent on the strength and direction of the wind, and the conformation of the shore. Along our own seaboard, the highest tides vary greatly between the most southern and northern parts. At Eastport, Me., the highest tides, when not affected by the wind, vary between twenty-five and thirty feet above the ordinary low water. At Boston they rise from eleven to twelve feet above the same point, under similar circumstances; and from New-York, following the line of the seaboard to Florida, they seldom rise above five feet.

763. Currents are principally caused by the tides, assisted, in some cases, by the wind. The theory of their action is simple. From the main current, which sweeps along the coast, secondary currents proceed into the *bays*, or indentations, in a line more or less direct, until they strike some point of the shore, from which they are deflected, and frequently separate into several others, the main branch following the general direction which it had when it struck the shore, and the others not unfrequently taking an opposite direction, forming what are termed *counter currents*, and, at points where the opposite currents meet, that rotary motion of the water known as *whirlpools*. The action of currents on the coast is to wear it away at those points against which they directly impinge, and to transport the débris to other points, thus forming, and sometimes removing, natural obstructions to navigation. These continual changes, caused by currents, make it extremely difficult to foresee their effects, and to foretell the consequences which will arise from any change in the direction, or the intensity of a current, occasioned by artificial obstacles.

764. A good theory of waves, which shall satisfactorily explain all their phenomena, is still a desideratum in science. It is known that they are produced by winds acting on the surface

of the sea; but how far this action extends below the surface and what are its effects at various depths, are questions that remain to be answered. The most commonly received theory is, that a wave is a simple oscillation of the water, in which each particle rises and falls, in a vertical line, a certain distance during each oscillation, without receiving any motion of translation in a horizontal direction. It has been objected to this theory that it fails to explain many phenomena observed in connection with waves.

In a recent French work on this subject, its author, Colonel Emy, an engineer of high standing, combats the received theory; and contends that the particles of water receive also a motion of translation horizontally, which, with that of ascension, causes the particles to assume an orbicular motion, each particle describing an orbit, which he supposes to be elliptical. He farther contends, that in this manner the particles at the surface communicate their motion to those just below them, and these again to the next, and so on downward, the intensity decreasing from the surface, without however becoming insensible at even very considerable depths; and that, in this way, owing to the reaction from the bottom, an immense volume of water is propelled along the bottom itself, with a motion of translation so powerful as to overthrow obstacles of the greatest strength if directly opposed to it. From this he argues that walls built to resist the shock of the waves should receive a very great batir at the base, and that this batir should be gradually decreased upward, until, towards the top, the wall should project over, thus presenting a concave surface at top to throw the water back. By adopting this form, he contends that the mass of water, which is rolled forward, as it were, on the bottom, when it strikes the face of the wall, will ascend along it, and thus gradually lose its momentum. These views of Colonel Emy have been attacked by other engineers, who have had opportunities to observe the same phenomena, on the ground that they are not supported by facts; and the question still remains undecided. It is certain, from experiments made by the author quoted upon walls of the form here described, that they seem to answer fully their intended purpose.

765. *Roadsteads.* The term *roadstead* is applied to an indentation of the coast, where vessels may ride securely at anchor under all circumstances of weather. If the indentation is covered by natural projections of the land, or *capes*, from the action of the winds and waves, it is said to be *land-locked;* in the contrary case, it is termed an *open* roadstead.

The anchorage of open roadsteads is often insecure, owing to violent winds setting into them from the sea, and occasioning high waves, which are very straining to the moorings. The

remedy applied in this case is to place an obstruction near the entrance of the roadstead, to break the force of the waves from the sea. These obstructions, termed *breakwaters*, are artificial islands of greater or less extent, and of variable form, according to the nature of the case, made by throwing heavy blocks of stone into the sea, and allowing them to take their own bed.

The first great work of this kind undertaken in modern times, was the one at Cherbourg in France, to cover the roadstead in front of that town. After some trials to break the effects of the waves on the roadstead by placing large conical shaped structures of timber filled with stones across it, which resulted in failure, as these vessels were completely destroyed by subsequent storms, the plan was adopted of forming a breakwater by throwing in loose blocks of stone, and allowing the mass to assume the form produced by the action of the waves upon its surface. The subsequent experience of many years, during which this work has been exposed to the most violent tempests, has shown that the action of the sea on the exposed surface is not very sensible at this locality at a depth of about 20 feet below the water level of the lowest tides, as the blocks of stone forming this part of the breakwater, some of which do not average over 40 lbs. in weight, have not been displaced from the slope the mass first assumed, which was somewhat less than one perpendicular to one base. From this point upwards, and particularly between the levels of high and low water, the action of the waves has been very powerful at times, during violent gales, displacing blocks of several tons weight, throwing them over the top of the breakwater upon the slope towards the shore. Wherever this part of the surface has been exposed the blocks of stone have been gradually worn down by the action of the waves, and the slope has become less and less steep, from year to year, until finally the surface assumed a slightly concave slope, which, at some points, was as great as ten base to one perpendicular.

The experience acquired at this work has conclusively shown that breakwaters, formed of the heaviest blocks of loose stone, are always liable to damage in heavy gales when the sea breaks over them, and that the only means of securing them is by covering the exposed surface with a facing of heavy blocks of hammered stone carefully set in hydraulic cement.

As the Cherbourg breakwater is intended also as a military construction, for the protection of the roadstead against an enemy's fleet, the cross section shown in (Fig. 175) has been adopted for it. Profiting by the experience of many years' observation, it was decided to construct the work that forms the cannon battery of solid masonry laid on a thick and broad bed of beton. The top surface of the breakwater is covered with heavy loose blocks

of stone, and the foot of the wall on the face is protected by large blocks of artificial stone formed of beton. The top of the battery is about 12 feet above the highest water level.

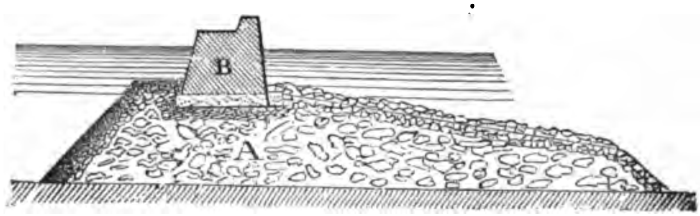


Fig. 175—Represents a section of the Cherbourg breakwater.
A, mass of stone.
B, battery of masonry.

The next work of the kind was built to cover the roadstead of Plymouth in England. Its cross section was, at first, made with an interior slope of one and a half base to one perpendicular, and an exterior slope of only three base to one perpendicular; but from the damage it sustained in the severe tempests in the winter of 1816–17, it is thought that its exterior slope was too abrupt.

A work of the same kind is still in process of construction on our coast, off the mouth of the Delaware. The same cross section has been adopted for it as in the one at Cherbourg.

All of these works were made in the same way, discharging the stone on the spot, from vessels, and allowing it to take its own bed, except for the facing, where, when practicable, the blocks were carefully laid, so as to present a uniform surface to the waves. The interior of the mass, in each case, has been formed of stone in small blocks, and the facing of very large blocks. It is thought, however, that it would be more prudent to form the whole of large blocks, because, were the exterior to suffer damage, and experience shows that the heaviest blocks yet used have at times been displaced by the shock of the waves, the interior would still present a great obstacle.

From the foregoing details, respecting the cross sections of breakwaters, which from experiment have been found to answer, the proper form and dimensions of the cross section in similar cases may be arranged. As to the plan of such works, it must depend on the locality. The position of the breakwater should be chosen with regard to the direction of the heaviest swells from the sea, into the roadstead,—the action of the current, and that of the waves. The part of the roadstead which it covers should afford a proper depth of water, and secure anchorage for vessels of the largest class, during the most severe storms; and vessels should be able to double the breakwater under all circumstances

of wind and tide. Such a position should, moreover, be chosen that there will be no liability to obstructions being formed within the roadstead, or at any of its outlets, from the change in the current which may be made by the breakwater.

766. The difficulty of obtaining very heavy blocks of stone, as well as their great cost, has led to the suggestion of substituting for them blocks of artificial stone, formed of concrete, which can be made of any shape and size desirable. This plan has been tried with success in several instances, particularly in a jetty or mole, at Algiers, constructed by the French government The beton for a portion of this work was placed in large boxes, the sides of which were of wood, shaped at bottom to correspond to the irregularities of the bottom on which the beton was to be spread. The bottom of the box was made of strong canvass tarred. These boxes were first sunk in the position for which they were constructed, and then filled with the beton.

767. *Harbors.* The term *harbor* is applied to a secure anchorage of a more limited capacity than a roadstead, and therefore offering a safer refuge during boisterous weather. Harbors are either *natural*, or *artificial.*

768. An artificial harbor is usually formed by enclosing a space on the coast between two arms, or dikes of stone, or of wood, termed *jetties*, which project into the sea from the shore, in such a way as to cover the harbor from the action of the wind and waves.

769. The plan of each jetty is curved, and the space enclosed by the two will depend on the number of vessels which it may be supposed will be in the harbor at the same time. The distance between the ends, or *heads*, of the jetties, which forms the mouth of the harbor, will also depend on local circumstances; it should seldom be less than one hundred yards, and generally need not be more than five hundred. There are certain winds at every point of a coast which are more unfavorable than others to vessels entering and quitting the harbor, and to the tranquillity of its water. One of the jetties should, on this account, be longer than the other, and be so placed that it will both break the force of the heaviest swells from the sea into the mouth of the harbor, and facilitate the ingress and egress of vessels, by preventing them from being driven by the winds on the other jetty, just as they are entering or quitting the mouth.

770. The cross section, and construction of a stone jetty differ in nothing from those of a breakwater, except that the jetty is usually wider on top, thirty feet being allowed, as it serves for a wharf in unloading vessels. The head of the jetty is usually made circular, and considerably broader than the other parts, as it, in some instances, receives a lighthouse, and a battery of can-

non. It should be made with great care, of large blocks of stone well united by iron, or copper cramps, and the exterior courses should moreover be protected by fender beams of heavy timber to receive the shock of floating bodies.

771. Wooden jetties are formed of an open frame work of heavy timber, the sides of which are covered on the interior by a strong sheeting of thick plank. Each rib of the frame (Fig. 176) consists of two inclined pieces, which form the sides

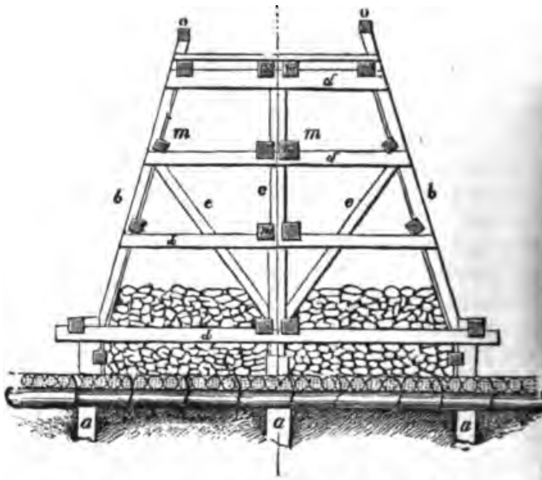


Fig. 176—Represents a cross section of a wooden jetty.
a, foundation piles.
b, inclined side pieces.
c, middle upright.
d, cross pieces bolted in pairs.
e, struts.
m, longitudinal pieces bolted in pairs.
o, parapet.

—of an upright centre piece,—and of horizontal clamping pieces, which are notched and bolted in pairs on the inclined and upright pieces; the inclined pieces are farther strengthened by struts, which abut against them and the upright. The ribs are connected by large string-pieces, laid horizontally, which are notched and bolted on the inclined pieces, the uprights, and the clamping pieces, at their points of junction. The foundation, on which this framework rests, consists usually of three rows of large piles driven under the foot of the inclined pieces and the uprights. The rows of piles are firmly connected by cross and longitudinal beams notched and bolted on them; and they are, moreover, firmly united to the framework in a similar manner. The interior sheeting does not, in all cases, extend the entire length of the sides, but open spaces, termed *clear-ways*, are often left, to

give a free passage and spread to the waves confined between the jetties, for the purpose of forming smooth water in the channel. If the jetties are covered at their back with earth, the clear ways receive the form of inclined planes.

The foundation of the jetties requires particular care, especially when the channel between them is very narrow. Loose stone thrown around the piles is the ordinary construction used for this purpose; and, if it be deemed necessary, the bottom of the entire channel may be protected by an apron of brush and loose stone.

The top of the jetties is covered with a flooring of thick plank, which serves as a wharf. A strong hand railing should be placed on each side of the flooring as a protection against accidents. The sides of jetties have been variously inclined; the more usual inclination varies between three and four perpendicular to one base.

772. Jetties are sometimes built out to form a passage to a natural harbor, which is either very much exposed, or subject to bars at its mouth. By narrowing the passage to the harbor between the jetties, great velocity is given to the current caused by the tide, and this alone will free the greater part of the channel from deposites. But at the head of the jetties a bar will, in almost every case, be found to accumulate, from the current along shore, which is broken by the jetties, and from the diminished velocity of the ebbing tides at this point. To remove these bars resort may be had, in localities where they are left nearly dry at low water, to reservoirs, and sluices, arranged with turning gates, like those adverted to for river improvements. The reservoirs are formed by excavating a large basin in-shore, at some suitable point from which the collected water can be directed, with its full force, on the bar. The basin will be filled at flood-tide, and when the ebb commences the sluice gates will be kept closed until dead low water, when they should all be opened at once to give a strong water chase.

773. In harbors where vessels cannot be safely and conveniently moored alongside of the quays, large basins, termed *wet-docks*, are formed, in which the water can be kept at a constant level. A wet-dock may be made either by an in-shore excavation, or by enclosing a part of the harbor with strong water-tight walls; the first is the more usual plan. The entrance to the basin may be by a simple sluice, closed by ordinary lock gates, or by means of an ordinary lock. With the first method vessels can enter the basin only at high tide; by the last they may be entered or passed out at any period of the tide. The outlet of the lock should be provided with a pair of guard gates, to be shut against very high tides, or in cases of danger from storms.

774. The construction of the locks for basins differs in nothing in principle, from that pursued in canal locks. The greatest care will necessarily be taken to form a strong mass free from all danger of accidents. The gates of a basin-lock are made convex towards the head of water, to give them more strength to resist the great pressure upon them. They are hung and manœuvred differently from ordinary lock gates; the quoin-post is attached to the side walls in the usual way: but at the foot of the mitre-post an iron or brass roller is attached, which runs on an iron roller way, and thus supports that end of the leaf, relieving the collar of the quoin-post from the strain that would be otherwise thrown on it, besides giving the leaf an easy play. Chains are attached to each mitre-post near the centre of pressure of the water, and the gate is opened, or closed, by means of windlasses to which the other ends of the chains are fastened.

775. The quays of wet-docks are usually built of masonry. Both brick and stone have been used; the facing at least should be of dressed stone. Large fender-beams may be attached to the face of the wall, to prevent it from being brought in contact with the sides of the vessels. The cross section of quay-walls should be fixed on the same principles as that of other sustaining walls. It might be prudent to add buttresses to the back of the wall to strengthen it against the shocks of the vessels.

776. Quay-walls with us are ordinarily made either by forming a facing of heavy round or square piles driven in juxtaposition, which are connected by horizontal pieces, and secured from the pressure of the earth filled in behind them by land-ties; or, by placing the pieces horizontally upon each other, and securing them by iron bolts. Land-ties are used to counteract the pressure of the earth or rubbish which is thrown in behind them to form the surface of the quay. Another mode of construction, which is found to be strong and durable, is in use in our Eastern seaports. It consists in making a kind of crib-work of large blocks of granite, and filling in with earth and stone rubbish. The bottom course of the crib may be laid on the bed of the river, if it is firm and horizontal; in the contrary case a strong grillage, termed a *cradle*, must be made, and be sunk to receive the stone work. The top of the cradle should be horizontal, and the bottom should receive the same slope as that of the bed, in order that when the stones are laid they may settle horizontally.

777. *Dikes*. To protect the lowlands bordering the ocean from inundations, dikes, constructed of ordinary earth, and faced towards the sea with some material which will resist the action of the current, are usually resorted to.

The Dutch dikes, by means of which a large extent of country has been reclaimed and protected from the sea, are the most re

markable structures of this kind in existence. The cross section of those dikes is of a trapezoidal form, the width at top averaging from four to six feet, the interior slope being the same as the natural slope of the earth, and the exterior slope varying, according to circumstances, between three and twelve base to one perpendicular. The top of the dike, for perfect safety, should be about six feet above the level of the highest spring tides, although, in many places, they are only two or three above this level.

The earth for these dikes is taken from a ditch in-shore, between which and the foot of the dike a space of about twenty feet is left, which answers for a road. The exterior slope is variously faced, according to the means at hand, and the character of the current and waves at the point. In some cases, a strong straw thatch is put on, and firmly secured by pickets, or other means; in others, a layer of fascines is spread over the thatch, and is strongly picketed to it, the ends of the pickets being allowed to project out about eighteen inches, so that they can receive a wicker-work formed by interlacing them with twigs; the spaces between this wicker-work being filled with broken stone; this forms a very durable and strong facing, which resists not only the action of the current, but, by its elasticity, the shocks of the heaviest waves.

The foot of the exterior slope requires peculiar care for its protection; the shore, for this purpose, is in some places covered with a thick apron of brush and gravel in alternate layers, to a distance of one hundred yards into the water from the foot of the slope.

On some parts of the coast of France, where it has been found necessary to protect it from encroachments of the sea, a cross section has been given to the dikes towards the sea, of the same form as the one which the shore naturally takes from the action of the waves. The dikes in other respects are constructed and faced after the manner which has been so long in practice in Holland.

778. *Groins.* Constructions, termed *groins*, are used whenever it becomes necessary to check the effect of the current along the shore, and cause deposites to be formed. These are artificial ridges which rise a few feet only above the surface of the beach, and are built out in a direction either perpendicular to that of the shore, or oblique to it. They are constructed either of clay, which is well rammed and protected on the surface by a facing of fascines or stones; or of layers of fascines; or of one or two rows of short piles driven in juxtaposition; or any other means that the locality may furnish may be resorted to; the object being to interpose an obstacle, which, breaking the force of the current, will occasion a deposite near it, and thus gradually cause the shore to gain upon the sea.

779. *Sea-walls.* When the sea encroaches upon the land forming a steep bluff, the face of which is gradually worn away, a wall of masonry is the only means that will afford a permanent protection against this action of the waves. Walls made for this object are termed *sea-walls.* The face of a sea-wall should be constructed of the most durable stone in large blocks. The backing may be of rubble or of beton. The whole work should be laid with hydraulic mortar.

APPENDIX.

Note A to Arts. Framing and Bridges.

Tubular Frames of Wrought Iron.—Except for the obvious application to steam boilers, sheet iron had not been considered as suitable for structures demanding great strength, from its apparent deficiency in rigidity; and although the principle of gaining strength by a proper distribution of the material, and of giving any desirable rigidity by combinations adapted to the object in view, were at every moment acted upon, from the ever-increasing demands of the art, engineers seem not to have looked upon sheet iron as suited to such purposes, until an extraordinary case occurred which seemed about to baffle all the means hitherto employed. The occasion arose when it became a question to throw a bridge of rigid material, for a railroad, across the Menai Straits; suspension systems, from their flexibility, and some actual failures, being, in the opinion of the ablest European engineers, unsuitable for this kind of communication.

Robert Stephenson, who for some years back has held the highest rank among English engineers, appears, from undisputed testimony, to have been the first to entertain the novel and bold idea of spanning the Strait by a tube of sheet iron, supported on piers, of sufficient dimensions for the passage within it of the usual trains of railroads. The preliminary experiments for testing the practicability of this conception, and the working out the details of its execution, were left chiefly in the hands of Mr. William Fairbairn, to whom the profession owes many valuable papers and facts on professional topics. This gentleman, who, to a thorough acquaintance with the mode of conducting such experiments, united great zeal and judgment, carried through the task committed to him; proceeding step by step, until conviction so firm took the place of apprehension, that he rejected all suggestions for the use of any auxiliary means, and urged, from his crowning experiment, reliance upon the tube alone as equal to the end to be attained.

Numerous experiments were made by him upon tubes of circular, elliptical, and rectangular cross section. The object chiefly kept in view in these experiments was, to determine the form of cross section which, when the tube

was submitted to a cross strain, would present an equality of resistance in the parts brought into compression and extension. It was shown, at an early stage of the operations, that the circular and elliptical forms were too weak in the parts submitted to compression, but that the elliptical was the stronger of the two; and that, whatever form might be adopted, extraordinary means would be requisite to prevent the parts submitted to compression from yielding, by "puckering" and doubling. To meet this last difficulty, the fortunate expedient was hit upon of making the part of the main tube, upon which the strain of compression was brought, of a series of smaller tubes, or cells of a curved or a rectangular cross section. The latter form of section was adopted definitively for the main tube, as having yielded the most satisfactory results as to resistance; and also for the smaller tubes, or cells, as most easy of construction and repair.

As a detail of each of these experiments would occupy more space than can be given in this work, that alone of the tube which gave results that led to the forms and dimensions adopted for the tubular bridges subsequently constructed, will be given in this place.

Model Tube.—The total length of the tube was 78 ft. The distance, or bearing between the points of support, on which it was placed to test its strength, was 75 ft. Total depth of the tube at the middle, 4 ft. 6½ in. Depth at each extremity, 4 ft. Breadth, 2 ft. 8 in.

The top of the tube was composed of a top and bottom plate, formed of pieces of sheet iron, abutting end to end, and connected by narrow strips riveted to them over the joints. These plates were 2 ft. 11½ in. wide. They were 6½ in. apart, and connected by two vertical side plates, and five interior division plates, with which they were strongly joined by angle irons, riveted to the division plates, and to the top and bottom plates where they joined. Each cell, between two division plates and the top and bottom plates, was nearly 6 in. wide. The sides of the tube were made of plates of sheet iron similarly connected; their depth was 3 ft. 6½ in. A strip of angle iron, bent to a curved shape, and running from the bottom of each end of the tube to the top just below the cellular part, was riveted to each side to give it stiffness. Besides this, precautions were finally taken to stiffen the tube by diagonal braces within it. The bottom of the tube was formed of sheets, abutting end to end, and secured to each other like the top plates; a continuous joint, running the entire length of the tube along the centre line of the bottom, was secured by a continuous strip of iron on the under side, riveted to the plates on each side of the joint. The entire width of the bottom was 2 ft. 11 in.

The sheet iron composing the top cellular portion was 0·147 in. thick; that of the sides 0·099 in. thick. The bottom of the tube at the final experiments, to a distance of 20 ft. on each side of the centre, was composed of two thicknesses of sheet iron, each 0·25 in. thick, the joints being secured by strips above and below them riveted to the sheets; the remainder, to the end of the tube, was formed of sheets 0·156 in. thick.

The total area of sheets composing the top cellular portion was 24·024 in.; that of the bottom plates at the centre portion, 22·450 in.

The general dimensions of the tube were one sixth those of the proposed structure. Its weight at the final experiment, 13,020 lbs.

The experiments, as already stated, were conducted with a view to obtain an equality between the resistances of the parts strained by compression and those extended; with this object, at the end of each experiment, the parts torn asunder at the bottom were replaced by additional pieces of increased strength.

The following table exhibits the results of the final experiments.

No. of Experiments.	Weight in lbs.	Deflection in inches
1	20,006	0·55
2	35,776	0·78
3	48,878	1·12
4	62,274	1·48
5	77,534	1·78
6	92,299	2·12
7	103,350	2·38
8	114,669	2·70
9	132,209	3·05
10	138,060	3·23
11	143,742	3·40
12	148,443	3·58
13	153,027	3·70
14	157,728	3·78
15	161,886	3·88
16	164,741	3·98
17	167,614	4·10
18	171,144	4·23
19	173,912	4·33
20	177,088	4·47
21	180,017	4·55
22	183,779	4·62
23	186,477	4·72
24	189,170	4·81
25	192,892	

The tube broke with the weight in the 25th experiment; the cellular top yielding by puckering at about 2 ft. from the point where the weight was applied. The bottom and sides remained uninjured.

The ultimate deflection was 4·89 in.

Britannia Tubular Bridge.—Nothing further than a succinct description of this marvel of engineering will be attempted here, and only with a view of showing the arrangement of the parts for the attainment of the proposed end. It differs in its general structure from the model tube, chiefly in having the bottom formed like the top, of rectangular cells, and in the means taken for giving stiffness to the sides.

The total distance spanned by the bridge is 1489 ft. This is divided into four bays, the two in the centre being each 460 ft., and the one at each end 230 ft. each.

The tube is 1524 ft. long. Its bearing on the centre pier is 45 ft.; that on the two intermediate 32 ft.; and that on each abutment 17 ft. 6 in. The height of the tube at the centre pier is 30 ft.; at the intermediate piers 27 ft.; and at the ends 23 ft. This gives to the top of the tube the shape of a parabolic curve.

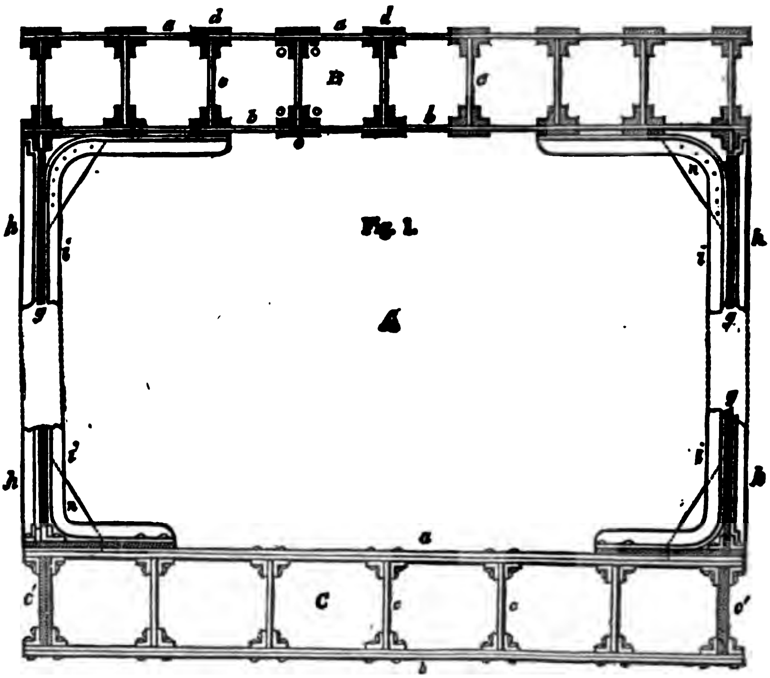


Fig. 1—Represents a vertical cross section of the Britannia Bridge.
A, interior of bridge.
B, cells of top cellular beam.
C, cells of bottom cellular beam.
a, top plates of top and bottom beams.
b, bottom plates of top and bottom beams.
c, division plates of top and bottom beams.
d and e, strips riveted over the joints of top and bottom plates.
o, angle irons riveted to a, b, and c.
g, plates of sides of the tube A.
h exterior T irons riveted over vertical joints of g.
i, interior T irons riveted over vertical joints of g, and bent at the angles of A, and extending beyond the second cell of the top beam, and beyond the first of the bottom beam.
n, triangular pieces on each side of i, and riveted to them

The cellular top (Fig. 1) is divided into eight cells *B*, by division plates *c*, connected with the top *a*, and bottom *b*, by angle irons o, riveted to the plates connected. The different sheets composing the plates *a* and *b* abut end to end lengthwise the tube; and the joints are secured by the strips *d* and *e*, riveted to the sheets by rivets that pass through the interior angle irons.

The sheets of which this portion is composed are each 6 ft. long, and 1 ft. 9 in. wide; those at the centre of the tube are $\frac{13}{16}$ths of an inch thick; they decrease in thickness towards the piers, where they are $\frac{10}{16}$ths of an inch thick. The division plates are of the same thickness at the centre, and decrease in the same manner towards the piers. The rivets are 1 in. thick, and are placed 3 in. apart from centre to centre. The cells are 1 ft. 9 in. by 1 ft. 9 in., so as to admit a man for painting and repairs.

The cellular bottom is divided into six cells *C*, each of which is 2 ft. 4 in. wide by 1 ft. 9 in. in height. To diminish, as far as practicable, the number of joints, the sheets for the sides of the cells were made 12 ft. long. To give sufficient strength to resist the great tensile strain, the top and bottom plates of this part are composed of two thicknesses of sheet iron, the one layer breaking joint with the other. The joints over the division plates are secured by angle irons o, in the same manner as in the cellular top. The joints between the sheets are secured by sheets 2 ft. 8 in. long placed over them, which are fastened by rivets that pass through the triple thickness of sheets at these points. The rivets, for attaining greater strength at these points, are in lines lengthwise of the cell. The sheets forming the top and bottom plates of the cells are $\frac{8}{16}$ths of an inch at the centre of the tube, and decrease to $\frac{7}{16}$ths at the ends. The division plates are $\frac{8}{16}$ths in the middle, and $\frac{8}{16}$ths at the ends of the tube. The rivets of the top and bottom plates are $1\frac{1}{8}$ in. in diameter.

Fig. 2.

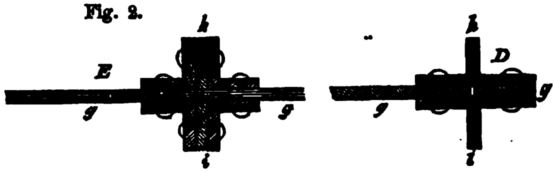


Fig 2—Represents a horizontal cross section of the T irons and side plates.
D, cross section near centre of bridge.
E, cross section near the piers.
g, plates of the sides.
h, exterior T irons.
i, interior T irons.

The sides of the tube (Fig. 2) between the cellular top and bottom are formed of sheets *g*, 2 ft. wide; the lengths of which are so arranged that there are alternately three and four plates in each pannel, the sheets of each pannel abutting end to end, and forming a continuous vertical joint between the adjacent pannels. These vertical joints are secured by strips of iron, *h* and *i*, of the T cross section, placed over each side of the joint, and

clamping the sheets of the adjacent pannels between them.' The T irons within and without are firmly riveted together with 1 in. rivets, placed at 3 in. between their centres. Over the joints, between the ends of the sheets in each pannel, pieces of sheet iron are placed on each side, and connected by rivets. The sheets of the pannels at the centre of the tube are $\frac{8}{16}$ths of an inch thick; they increase to $\frac{10}{16}$ths to within about 10 ft. of the piers, where their thickness is again increased; and the T irons are here also increased in thickness, being composed of a strip of thick sheet iron, clamped between strips of angle iron which extend from the top to the bottom of the joints. The object of this increase of thickness, in the pannels and T irons at the piers, is to give sufficient rigidity and strength to resist the crushing strain at these points.

The T irons on the interior are bent at top and bottom, and extended as far as the third cell from the sides at top, and to the second at bottom. The projecting rib of each in the angles is clamped between two pieces, *n*, of sheet iron, to which it is secured by rivets, to give greater stiffness at the angles of the tube.

The arrangement of the ordinary T irons and sheets of the pannels is shown in cross section by *D*, Fig. 2; and that of the like parts near the piers by *E*, same Fig.

For the purpose of giving greater stiffness to the bottom, and to secure fastenings for the wooden cross sleepers that support the longitudinal beams on which the rails lie, cross plates of sheet iron, half an inch thick, and 10 in. in depth, are laid on the bottom of the tube, from side to side, at every fourth rib of the T iron, or 6 ft. apart. These cross plates are secured to the bottom by angle iron, and are riveted also to the T iron.

The tube is firmly fixed to the central pier, but at the intermediate piers and the abutments it rests upon saddles supported on rollers and balls, to allow of the play from contraction and expansion by changes of temperature.

The following tabular statements give the details of the dimensions, weights, &c., of the Britannia Bridge.

	Feet.	Plates	Angle iron.	T iron.	Rivet iron.	Cast iron	Total.
		tons.	tons.	tons.	tons.	tons.	tons.
Total length of each tube	1524						
" " of tubes for each line	3048						
Greatest span of bay	460						
Height of tubes at the middle	30						
" " intermediate piers	27						
" " ends	23						
Extreme width of tubes	14½						
Number of rivets in one tube	862,000						
Computed weight of tube 274 ft. long	....	450	109	70	60		689
" " 3 tubes 274 ft. long	....	1350	327	210	180		2067
" " 1 tube 472 ft. long	....	965	188	139	108		1400
" " 3 tubes 472 ft. long	....	2895	564	417	324		4200
" " 1 tube over pier 32ft. long	....	64	26	10	7		107
" " " " "	....	64	26	10	7		107
Frames and beams	....	....	....	....	....	2000	2000
Total weight	....	5788	1240	856	686	2000	10,570

Formula for reducing the Breaking Weight of Wrought Iron Tubes.

Representing by A, the total area in inches of the cross section of the metal.
" " *d*, the total depth in inches of the tube.
" " *l*, the length in inches between the points of support.
" " C, a constant to be determined by experiment.
" " W, the breaking weight in tons.

Then the relations between these elements, in tubes of cylindrical, elliptical and rectangular cross section, will be expressed by

$$W = C\frac{A\,d}{l}.$$

The mean value for C for cylindrical tubes, deduced from several experiments, was found to be 13·03; that for elliptical tubes, 15·3; and that for rectangular tubes, 21·5.

Note B to Art. Roads.

Plank-Roads.—A road covering, consisting of thick boards, or planks, resting on longitudinal beams, or sleepers, and known as *Plank-Roads*, has, within the past few years, been introduced among us; and from its adaptation to our uncleared forest districts, its superior economy to the ordinary road coverings in such localities, and its intrinsic merits, as fulfilling the requisites of a good road covering, is rapidly coming into extensive use throughout all parts of our country.

Fig A

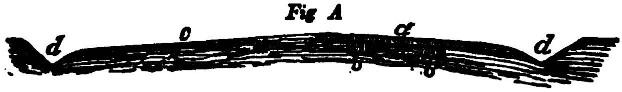


Fig B

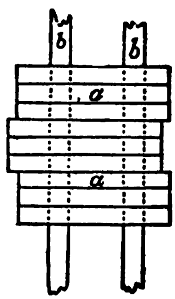


Fig. *A*—Represents a cross-section.
Fig. *B*—A plan of a plank road.
a a, board surface.
b b, sills.
c, summer road.
d d, side surface drains.

The method most generally adopted in constructing plank-roads consists in laying a flooring, or track, eight feet wide, composed of boards from nine to twelve inches in width, and three inches in thickness, which rest upon two parallel rows of sleepers, or sills, laid lengthwise of the road, and having their centre lines about four feet apart, or two feet from the axis of the road. Sills of various sized scantling have been used, but experience seems in favor of scantling about twelve inches in width, four inches in thickness, and in lengths of not less than fifteen to twenty feet. Sills of these dimensions, laid flatwise, and firmly embedded, present a firm and uniform bearing to the boards, and distribute the pressure they receive over so great a surface, that, if the soil upon which they rest is compact and kept well drained, there can be but little

settling and displacement of the road surface, from the usual loads passing over it. The better to secure this uniform distribution of the pressure, the sills of one row are so laid as to break joints with the other; and to prevent the ends of the sills from yielding the usual precaution is taken to place short sills at the joints, either beneath the main sills, or on the same level with them.

The boards are laid perpendicular to the axis of the road, experience having shown that this position is as favorable to their wear and tear as any other, and is otherwise the most economical. Their ends are not in an unbroken line, but so arranged that the ends of every three or four project alternately, on each side of the axis of the road, three or four inches beyond those next to them, for the purpose of presenting a short shoulder to the wheels of vehicles, to facilitate their coming upon the plank surface, when from any cause they may have turned aside. On some roads the boards have been spiked to the sills; but this is, at present, regarded as unnecessary, the stability of the boards being best secured by well packing the earth between and around the sills, so as to present, with them, a uniform bearing surface to the boards, and by adopting the usual precautions for keeping the subsoil well drained, and preventing any accumulation of rain water on the surface.

The boards for plank-roads should be selected from timber free from the usual defects, such as knots, shakes, &c., which would render it unsuitable for ordinary building purposes; as durability is an essential element in the economy of this class of structures. So far as experience has furnished data, boards of three inches in thickness offer all the requisites of strength and durability that can be obtained from timber in its ordinary state, in which it is used for plank-roads.

Besides the wooden track of eight feet, an earthen track of twelve feet in width is made, which serves as a summer road for light vehicles, and as a turn out for loaded ones; this, with the wooden track, gives a clear road surface of twenty feet, the least that can be well allowed for a frequented road. It is recommended to lay the wooden track on the right hand side of the approach of a road to a town, or village, for the proper convenience of the rural traffic, as the heavy trade is to the town. The surface of this track receives a cross slope from the side towards the axis of the road outwards of 1 in 32. The surface of the summer road receives a cross slope in the opposite direction of 1 in 16. These slopes are given for the purpose of facilitating a rapid surface drainage. The side drains are placed for this purpose parallel to the axis of the road, and connected with the road surface in a suitable slope.

Where, from the character of the soil, good summer roads cannot be had, it will be necessary to make wooden turn outs, from space to space, to prevent the inconvenience and delay of miry roads. This it is proposed to do by laying, at these points, a wooden track of double width, to enable vehicles meeting to pass each other. It is recommended to lay these turn outs on four or five sills, to spring the boards slightly at the centre, and spike their ends to the exterior sills.

The angle of repose, by which the grade of plank-roads should be regu-

lated, has not yet been determined by experiment; but as the wooden surface is covered with a layer of clean sand, fine gravel, or tan bark, before it is thrown open to vehicles, and as it in time becomes covered with a permanent stratum of dust, &c., it is probable that this angle will not materially differ from that on a road with a broken stone surface, like the one of McAdam, or of Telford, when kept in a thorough state of repair.

In some of the earlier plank-roads made in Canada, a width of sixteen feet was given to the wooden track, the boards of which were laid upon four or five rows of sills; experience soon demonstrated that this was by no means an economical plan, as it was found that vehicles kept the centre of the wooden surface, which was soon worn into a beaten track, whilst the remainder was but slightly impaired. This led to the abandonment of the wide track for the one now usually adopted, which answers all the ends of the wants of travel, and is much more economical, both in the first outlay and for subsequent renewals.

The great advantages of plank-roads over every other kind, in a densely wooded country, for the rural traffic, are so obvious, that, did not experience teach us by what mere accidents, apparently, improvements of the most important kind have been suggested and carried into effect, it might be a subject of astonishment that they had not been among the first to be introduced, after a trial of the old *corduroy* road, so generally resorted to in the early stages of road-making in this country.

Note C to Arts. 441 *and* 442.

Methods of describing Curves composed of Arcs of Circles.—The span and rise of an arch being given, together with the directions of the tangents to the curve at the springing lines and crown, an infinite number of curves, composed of arcs of circles, can be determined, which shall satisfy the conditions of forming a continuous curve, or one in which the arcs shall be consecutively tangent to each other, and such that those at the springing lines and the crown shall be tangent to the assumed directions of the tangents to the curve at those points. To give a determinate character to the problem, in each particular case, certain other conditions must be imposed, upon which the solution will depend.

When the tangents to the curve at the springing lines and crown are respectively perpendicular to the span and rise, the curve satisfying the above general conditions will belong to the class of oval or basket-handle curves; when the tangents at the springing lines are perpendicular to the span, and those at the crown are oblique to the rise, the curves will belong to the class of pointed or obtuse curves.

In the class of ovals, when the rise is not less than one third of the span, the oval of three centres will generally give a curve of a more pleasing form to the eye than one of a greater number of centres; when the rise is less than a third of the span, a curve of five, seven, or a greater odd number of centres will give, under this point of view, a more satisfactory solution. In the pointed and obtuse curves the number of centres is even, and is usually restricted to four.

Three Centre Curves. To obtain a determinate solution in this case it will be necessary to impose one more condition, which shall be compatible with the two general ones of having the directions of the tangents at the springing lines and crown fixed. One of the most simple, and at the same time admitting of a greater variety of curves to choose from, is to assume the radius of the curve at the springing lines. In order that this condition shall be compatible with the other two, the length assumed for this must lie between zero and the rise of the arch; for were it zero there would be but one centre, and if taken equal to the rise the radius of the curve at the crown would be infinite.

Let $A\ D$ (fig. A) be the half span, and $A\ C$ the rise. Having prolonged $C\ A$ indefinitely, take any distance less than $A\ C$, and set it off from D to R, along $A\ D$; and from C to P, along $A\ C$. Join R and P, which distance bisect by a perpendicular. Prolong the perpendicular, to intersect the indefinite prolongation of $C\ A$. Through this point of intersection S, and the point R, draw an indefinite line. From R, as a centre, with the radius $R\ D$, describe an arc, which prolong to Q to intersect $S\ R$ prolonged. From S, as a centre, with the radius $S\ Q$, describe an arc, which, from the construction, must pass through

the point C, and be tangent to the first arc at Q. The centres R and S, thus determined, and the curve $D\,D\,C$ deduced from them, will satisfy the imposed conditions.

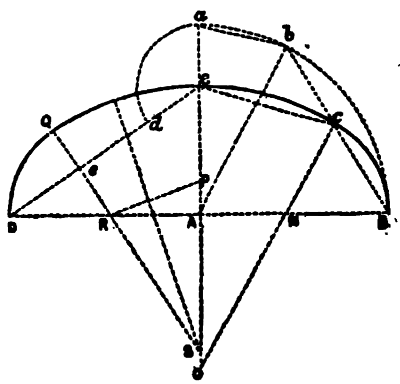


Fig. A.

The two following constructions, from their simplicity and the agreeable form of curve which they produce, are in frequent use. The first consists in imposing the condition that each of the three arcs shall be of 60°; the second, that the ratio $\frac{R}{r}$ between the radii of the arcs at the crown and springing line shall be a minimum.

To construct the curve satisfying the former condition, let $A\,B$ be the half span, and $A\,C$ the rise. With the radius $A\,B$ describe $A\,a$ of 90°,—set off on it $B\,b = 60°$,—draw the lines $a\,b$, $b\,B$ and $A\,b$,—from C draw a parallel to $a\,b$, and mark its intersection c with $b\,B$,—from c draw a parallel to $A\,b$, and mark its intersections N and O with $A\,B$, and $C\,A$ prolonged. From N with the radius $N\,B$ describe the arc $B\,c$,—from O with the radius $O\,c$ describe the arc $C\,c$. The curve $B\,c\,C$ will be the half of the one satisfying the given conditions; and N and O two of the centres.

To construct the curve satisfying the second condition, or $\dfrac{d\left(\frac{R}{r}\right)}{d\,r} = o$. Let $A\,D$ be the half span,—$A\,C$ the rise. Draw $D\,C$, and from C set off on it $C\,d = C\,a$, equal to the difference between the half span and rise. Bisect the distance $D\,d$ by a perpendicular, which prolong to intersect $D\,A$, and $C\,A$ prolonged, at R and S,—from these points, as centres, with the radii $R\,D$ and $S\,Q$, describe the arcs $D\,Q$ and $Q\,C$; and the curve $D\,Q\,C$ will be the half of the one required.

The analysis, from which the above result is obtained, is of a very simple character; for designating by $R = S\,C$ the greater radius, by $r = R\,D$ the

cases,—by $a = AD$ the half span, and by $b = AC$ the rise, there results, from the right angled triangle SAR,

$$\overline{SR}^2 = \overline{AS}^2 + \overline{AR}^2,$$

or

$$(R - r)^2 = (R - b)^2 + (a - r)^2,$$

from which is obtained

$$\frac{R}{r} = \frac{a^2 + b^2 - 2ar}{(2b - 2r)r}.$$

Differentiating this expression, and placing its first differential coefficient equal to zero, or making $\frac{d\left(\frac{R}{r}\right)}{dr} = 0$, there results, after the terms are reduced,

$$r = \frac{a^2 + b^2 - (a - b)\sqrt{a^2 + b^2}}{2a} = \frac{\sqrt{a^2 + b^2}}{a}\cdot\left(\frac{\sqrt{a^2 + b^2} - (a - b)}{2}\right),$$ but

$\sqrt{a^2 + b^2} = DC$, and $\sqrt{a^2 + b^2} - (a - b) = Dd$, hence the given construction for the centres required.

By comparing the two methods just explained, for the same span and rise it will be seen that the former gives a curve in which the lengths of the arcs differ less than in the latter, and which is therefore more agreeable to the eye.

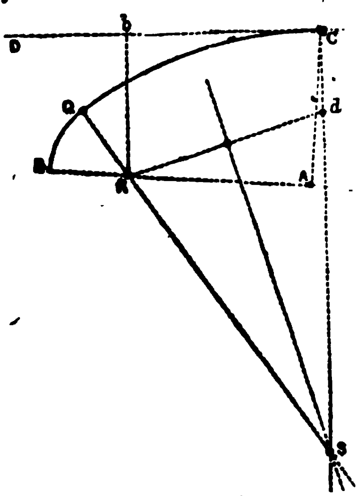


Fig. 2.

Obtuse and Pointed Curves of Four Centres.—Let AB be the half span,—AC the rise of the required curve,—and CD the direction of the tangent to it at the crown. At C draw a perpendicular to CD. Take any point R on AB, such that RB shall be less than the perpendicular Rb, from R upon the tangent CD. From C, on the perpendicular to CD, set off Cd, equal to the assumed distance RB,—draw Rd, and bisect it by a perpendicular,—which prolong to intersect the one from C at the point S,—through S and R draw a line,—from R, with the radius RB, describe an arc, which prolong to Q, to intersect the line through S and R,—from S with the radius SQ, describe an arc, which will be tangent to the first at Q, and pass through C. The curve BQC will be the half of the one required to satisfy the given conditions.

The analogy between this construction and the one first given for three

centre curves will be readily seen by comparing the constructions for the two *Five Centre Oval Curves, &c.* When the rise is less than one third of the span, it is found that oval curves of a pleasing shape cannot be obtained by using only three centres, and five, or a greater odd number of centres must be resorted to. Besides the two general conditions common to all ovals, a greater number of particular ones must be imposed, as the number of centres is increased, restricting them within the limits of compatibility with each other and with the two common to all. By imposing, for example, on the oval of five centres, the conditions that the radii of the two consecutive arcs from the springing line shall be assumed as the particular conditions, a very simple construction, analogous to the one for ovals of three centres, will show the limits within which these must be restricted, not to interfere with the others that are common to all. Without stopping to illustrate this by an example, which will present no difficulty to any one tolerably conversant with the elements of geometry to make out alone, a more general method will be given, applicable alike to all curves of this class.

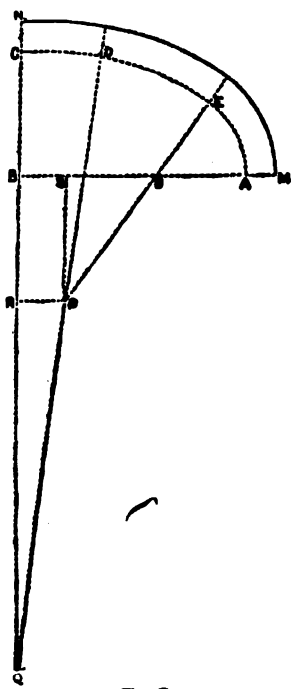


Fig. C.

The half span and rise being given, let it be required to determine an oval of five centres with the particular conditions, that the radii of the consecutive arcs, from the springing line towards the crown, shall be in an increasing geometrical progression,—in which case the curvatures of the arcs will be in a decreasing geometrical progression—and the lengths of the consecutive arcs shall increase in a given ratio. Designate the half span AB by p (Fig. C), the rise by q,—the ratio of the radii by m,—the ratio of the arcs by n, and the number of degrees in the arc at the springing line by a. Suppose the centres O, P and Q found, and draw PS perpendicular to AB,—and PR perpendicular to BC produced.

The radii OA, PE and QD will be represented respectively by r, rm, and rm^2,—and the angles AOE, EPD, and DQC, between them by

$$a, a\frac{n}{m}, \text{ and } a\frac{n^2}{m^2}; \text{ —}$$

now, from the properties of the figure, the following equations are obtained

$$a + a\frac{n}{m} + a\frac{n^2}{m^2} = 90^\circ \quad . \quad . \quad . \quad (A)$$

$$AB = p = r + OS + PR \quad . \quad . \quad (B)$$

$$BC = q = rm^2 - (PS + QR), \quad . \quad (C)$$

From the right angle triangle OPS, and PQR, there results,

$$OS = OP \cos. a = (rm - r) \cos. a;$$
$$PS = OP \sin. a = (rm - r) \sin. a;$$

$$PR = PQ \cos. (a + a\frac{n}{m} + (rm^2 - rm) \cos. (a + a\frac{n}{m});$$

$$QR = PQ \sin. \left(a + a\frac{n}{m}\right) = (rm^2 - rm) \sin. \left(a + a\frac{n}{m}\right)$$

by substituting these values in equations (B) and (C), there results,

$$p = r \left\{ 1 + (m - 1) \cos. a + (m^2 - m) \cos. \left(\frac{m+n}{m}\right) a \right\} \qquad (E)$$

$$q = r \left\{ m^2 - (m - 1) \sin. a - (m^2 - m) \sin. \left(\frac{m+n}{m}\right) a \right\}; \qquad (F)$$

and by reduction, equation (A) becomes,

$$a = \frac{(m - n)\, m^2}{m^3 - n^3} 90^\circ; \quad . \quad . \quad . \quad . \quad . \quad (G)$$

The equations (E), (F) and (G) express, therefore, the relations which subsist between the six quantities p, q, r, a, m and n when the imposed conditions are satisfied. Let three of these quantities as m, n and r be assumed, the others will be found from the three equations in question; that is the span, rise, and number of degrees in the arc at the springing line, which correspond to the given values.

From the solution here given, the ratio of p to q or $\frac{p}{q}$ is found; but as the rise and span are usually a part of the data, this ratio $\frac{p}{q}$ may be different from that $\frac{b}{c}$ of the given half span b, and rise c; in which case it will be necessary to assume new values for the quantities m, n, and r, and find the corresponding values of p, q, and a, until the ratio $\frac{p}{q}$ is equal to, or nearly the same as $\frac{b}{c}$. When a suitable approximation has been obtained, it will be easy to find a curve which shall differ but little from the required one, and whose half span and rise shall have the required ratio $\frac{b}{c}$.

To effect this, let x be the quantity which must be added to p and q respectively, to make their ratio the same as that of b to c; this condition will be expressed by the equation,

$$\frac{b}{c}=\frac{p+x}{q+x},$$

from which there results

$$x=\frac{pc-qb}{b-c}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (H)$$

if now this quantity be set off from A to M (Fig. C), and from C to N, and a new curve AN be described from the same centres O, P and Q, it will be parallel to the curve AC, whose half span and rise are p and q, and the half span BM, and rise BN, will have the same ratio as b to c. To pass from this curve to a similar one, described on the given half span b, and rise c, it will be only necessary to multiply each line of the figure $QPOMN$ by the ratio

$$\frac{b}{p+x};$$

or, substituting for x its value, as determined in equation (H), by

$$\frac{b-c}{p-q},$$

since the figures being similar, their homologous lines are proportional, or, for example,

$$p+x:b::OM:\frac{b}{p+x}\,OM;$$

which will give the line, corresponding to OM, in the figure of which b is the half span, and c the rise.

The method here explained may be applied to any number of centres, but where the rise is less than one-fourth of the span, an oval of five centres will be found to answer fully all the required conditions.

There are other methods of describing the oval of five, or a greater number of centres, which are rather more simple for calculation than the general method just given.

By assuming, for example, the greatest and smallest radii within suitable limits, the intermediate radius may receive the condition of being a mean proportional between these two; or designating it by x, there will result $x=\sqrt{R\times r}$; —R being the greatest radius, and r the least. Having found x, the position of the intermediate centre P is found, by describing an arc from Q with a radius $R-x$, and another from O with a radius $x-r$, and taking their point of intersection P.

A similar process might be followed for an oval of seven centres, by finding the two intermediate terms of a geometrical progression, of which r and R are the two extremes.

Note D to Arts. 270, &c., on the Strength of Materials.

Elasticity and Cohesion, and their Measure.—To arrive at somewhat definite notions on the subjects of the elasticity, and the tenacity or cohesion of solid bodies, and the measure of the resistance which they respectively offer to any extraneous force that tends to disturb the natural state of equilibrium of the elementary particles of which these bodies are composed, and thereby call into play their elasticity and cohesion, it may be well to give a brief summary of the hypotheses now most generally received among writers on physics upon these points; and to show in what manner the relations between the disturbing forces and their effects can be represented geometrically.

The hypotheses now generally admitted are that bodies are composed of elementary molecules, each of which consists of atoms grouped together in definite numbers or proportions according to simple and regular natural laws; that the positions of the atoms of any molecule, with respect to each other, cannot be so far displaced by any ordinary extraneous force as to modify their arrangement, external form, or mechanical properties; that the elementary molecules, separated from each other by greater or lesser distances, as compared with their own dimensions, exert a reciprocal attraction, which varies in intensity not only with their distances apart, but also with their relative positions, and that the tendency of this reciprocal attraction is to cause the molecules to group themselves according to regular laws; that, in the natural state of equilibrium of the molecules, the forces of attraction are balanced by the forces of repulsion of the interposed caloric, but that these forces may be brought into play by any extraneous force which tends to disturb the natural state of equilibrium of the molecules, either by its tendency to separate them, or to press them together, until they have assumed a new position of stable equilibrium under the combined effect of all the forces in action.

To account for the state of equilibrium of the molecules under the action of the forces of attraction and repulsion alone, it is supposed that the atoms of caloric repel each other at all distances, but with a force that decreases very rapidly in intensity as the distance between the molecules increases;—that the atoms of caloric on the contrary are attracted by the molecules of different bodies with varying intensities, and which causes them to collect around these molecules, so as to surround each one with a kind of atmosphere of caloric that decreases in density from the centre outwards, until it attains an intensity equal to that of the surrounding medium;—that, when two molecules of a body are brought so near each other as to be within the sphere of these forces of attraction and repulsion, the force by which they are repelled is simply that between the atoms of caloric, whilst the one by which they are attracted to each other is composed of the mutual attraction of their matter, and of the attraction of the atoms of the caloric composing the atmosphere of the one for the matter of the other;—finally, that the intensities of these forces of attrac-

tion and repulsion decrease very rapidly as the distance between the molecules is increased, and so as to become null, or insensible at distances which are appreciable by the senses.

Admitting then the hypothesis, that, in the ordinary state of equilibrium of solid bodies, the molecules are preserved in their relative positions by a force of attraction and one of repulsion which balance, or destroy each other, and that when the distance at which they are kept apart in this state is either increased or decreased by an extraneous force, acting in the line of direction between their centres, the force of attraction, or that of repulsion will be called into action, the one or the other being in excess, as the extraneous force tends to separate or press together the molecules, the extraneous force itself measuring this excess, it will be easy to represent these conditions of equilibrium generally, and to express the law by which these various forces are connected.

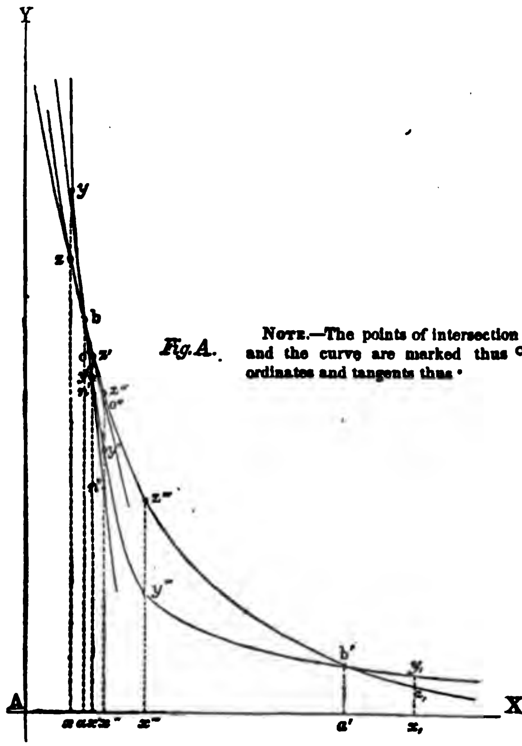


Fig. A.

NOTE.—The points of intersection of the ordinates and the curve are marked thus ○; those of the ordinates and tangents thus •

To do this let A X, and A Y (Fig. A), be taken as the rectangular axes of a curve y, y', y'', &c., the abscissas of which, as A x, A x', A x'', &c., represent

the respective distances apart of two molecules, and the corresponding ordinates $x\,y$, $x'\,y'$, $x''\,y''$, &c., the corresponding values of the forces of repulsion, and let z, z', z'', &c., be a second curve having the same abscissas as the first, and for its ordinates $x\,z$, $x'\,z'$, $x''\,z''$, &c., which represent the values of the forces of attraction corresponding to the distances apart of the molecules, A x, A x' &c. These two curves should intersect at some point, as b, which corresponds to the natural state of equilibrium of the two molecules, in which their distance apart is A a, and the forces of repulsion and attraction, represented by the ordinate $a\,b$, are equal. From the common point b, towards the axis A Y, the two curves should approach rapidly this axis, without however ever meeting it, since matter is impenetrable, and in this part the forces of repulsion represented by the ordinates $x\,y$, &c., will be greater than those of attraction, represented by the ordinates $x\,z$, &c. To the right of the point b, the curves will recede from each other making the ordinates $x\,z$, &c., greater than the corresponding ones $x\,y$, &c., until some distance A x'' between the molecules is reached, when the difference $z''\,y$ between the corresponding ordinates is a maximum, and from which point the curves will again approach each other, to intersect at a second point b', having the common ordinate $a'\,b'$, where the forces are again in equilibrium, and beyond which, to the right, that of repulsion again exceeds the one of attraction. If, beyond this point b', the force of repulsion still continues the greater, the curves will separate more and more, and will approach the axis A X without ever attaining it, so that at some distance A $x_{,}$, infinitely great with respect to the one A a, corresponding to the natural state of equilibrium, the corresponding ordinates $x_{,}\,z_{,}$, and $x_{,}\,y_{,}$, will be infinitely small with respect to the one $a\,b$.

Examining now what takes place in the vicinity of the point b, when the natural state of equilibrium is slightly disturbed by any extraneous force, it will be observed that when the force acts to increase the primitive distance A a between the molecules, so as to make it A $a + a\,x'$ for example, then the length $y'\,z' = x'\,z' - x'\,y'$ will represent the value of this force, and is the intensity of the resistance offered by the force of attraction to the displacement $a\,x'$ of the molecule. In like manner, it will appear that $x\,y$ measures the intensity of the force of repulsion to an extraneous force that would displace the molecule the distance $a\,x$. It will be further observed, on an examination of the curves, that the measure of the intensity of the resistance, offered by the force of attraction to the displacement of the molecule, will gradually increase with the displacement, until it attains a maximum state $z'''\,y'''$, corresponding to the displacement A x''', from which point it will decrease to the point b', the new position of equilibrium of the molecules.

From what has been thus far stated, a clear idea may be formed of the elastic resistance offered by the two molecules to any force which tends to displace them from their state of natural equilibrium, and the law between this resistance and the corresponding displacement within the range of elasticity. For let any extraneous force be applied to separate or bring together the two molecules, the intensity of this force being less than the maximum resistance $y'''\,z'''$, its effect will be to change the distance between the molecules, until

they have gained a new position, where all the forces will be again in equilibrium. Let this position be the one corresponding to A x' for example; now so long as the extraneous force acts, the molecules will retain their respective positions apart, A and x'; if the extraneous force be suddenly withdrawn the molecules will approach each other to regain their primitive distance apart A a, with a certain velocity, which velocity, or rather the living force accumulated, will cause the molecules to approach nearer to each other than the distance A a, passing which the force of repulsion will be brought into play, and by its resistance, having destroyed the living force gained, will cause the molecules to recede from each other, creating in turn a certain amount of living force, and they will thus continue to oscillate between their primitive positions until they are finally brought to rest with respect to each other in it by extraneous resistances.

If a tangent be drawn to each of the curves y, y', &c., and z, z', &c., at their common point b, these tangents will, like the curves, intersect at b, and will each coincide with its corresponding curve, for a greater or smaller distance on each side of the point b. Now, if any distances $a\,x'$, $a\,x''$, &c., be taken on each side of a, and be considered infinitely small with respect to Aa, the primitive distance apart of the molecules, the portions of the ordinates to the curves as $n'\,o'$, $n''\,o''$, at these points, intercepted between the tangents, will be equal to the portions of the same ordinates intercepted between the curves, as the curves and their tangents are taken as coinciding along the portions corresponding to $a\,x$, $a\,x''$, &c. The intercepted portions of the ordinates, with the portions of the tangents, as $b\,n'$, $b\,n''$, intercepted between them and the point b, will form similar triangles, from which is readily deduced that the portions of the intercepted ordinates are proportional respectively to the corresponding distances $a\,x'$, $a\,x''$, &c.; or, in other words, that the forces with which the molecules attract, or repel each other, for infinitely small displacements, as compared with the primitive distance of natural equilibrium, are proportional to the displacements. But since the ratio $\frac{n'\,o'}{a\,x'} = \frac{n''\,o''}{a\,x''}$, between the portions of the ordinates intercepted between the tangents and the corresponding displacement is constant, it may be taken to express the numerical value of the resistance offered by the molecules, in their position of natural equilibrium, to the infinitely small displacements in which the tangents coincide with the elements of the curve; which amounts to saying, that, for infinitely small displacements of the molecules of a body, the value of the elastic force remains sensibly constant.

It will be readily seen, from an examination of Fig. A, that, in proportion as the two curves approach more nearly to coincide with the ordinate $a\,b$, the angle between the tangents will be the smaller, and the distances $a\,x'$, $a\,x''$ &c., will also be the smaller, as compared with the corresponding parts of the ordinates $n'\,o'$, $n''\,o''$, &c., intercepted between the tangents; and the elastic resistance, or rigidity of the molecules, measured by the constant ratio $\frac{n'\,o'}{a\,x'}$, will be the greater.

Relation between the Elongation, or Compression, and the Force or Strain, by which it is caused, in the use of a rod, or bar of a given cross section, the force acting in the direction of the length of the bar.

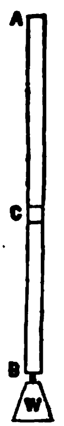


Fig. B.

Let the original length of the bar be represented by L; the area of its cross section by A; by W the force acting in the direction of the length of the bar; which force, regarding the weight of the bar as inconsiderable with respect to W, may be considered as a weight suspended from the lower end of the bar; and by l the elongation of L due to W. Now whether the bar be supposed to consist of as many parallel fibres as there are equidistant molecules in the section A, each fibre being of the length L, or whether it be supposed divided into a number of infinitely thin slices of the same thickness, to the extremities of each of which a force W is so applied that its effort will be uniformly distributed over each element of the area A of the slice; it will be apparent, from a moment's consideration, that the resistance offered by the bar to elongation will be independent of its length, and proportional to the number of fibres, or to the area A; that the elongations of the different portions of the length of the bar, arising from the action of W, will be directly proportional to their original lengths, so that the total elongation will be proportional to the total length of the bar; and the resistance arising from elasticity will be measured, as in the case of the displacement of two molecules, by the ratio between the very small and proportional displacement of two molecules of the same fibre, and the force by which this displacement is produced.

As L is the original length, and l the total elongation, the proportional elongation, or that which takes place for each foot, or other unit in which L is expressed, is represented by the fraction $\frac{l}{L} = \lambda$, and is the same for every fibre of the bar. The measure of the elastic resistance therefore will be $\frac{W}{\lambda}$. Representing by E the measure of the elastic resistance on a unit of the surface A, the measure of the total resistance on this surface will be $E \times A$.

From this is obtained the relation

$$\frac{W}{\lambda} = E \times A; \text{ or } W = E\,A\,\lambda = E\,A\,\frac{l}{L},$$

from which W or l may be found when the other is known.

By making A equal to unity of area, and $l = L$, the above relation becomes $W = E$. In other words, E is the force which applied to a bar, the area of the cross sections of which being unity, would elongate the bar a quantity equal to its original length. This quantity E is termed by writers the *coefficient*, or *the modulus of elasticity*.

The reasoning here used for the circumstances of elongation will equally apply, from what precedes, to the case of the shortening of a bar by a force of compression.

To find the relations between the elongation and strain when the weight of the bar is taken into consideration.

Represent by L the original length, before elongation, of a bar A B (Fig. B); by x the length A C of any portion of it, estimated from A; by dx an element of the part x; by W the weight suspended at B; and by w the unit of weight of the material of the bar.

The weight of the portion of the bar B C, and which tends to elongate the part A C above it, will be expressed by

$$(L - x)\,wA;$$

the total force, or strain, acting at the point C, will therefore be expressed by

$$W + (L - x)\,wA;$$

and the effect of this strain on the element, represented in length by dx will be, from the preceding proportions, to produce an elongation expressed by

$$\frac{W + (L - x)\,wA}{EA}\,dx;$$

the total length of the element dx after elongation will therefore be

$$dx + \frac{W + (L - x)\,wA}{EA}\,dx;$$

Integrating this expression between the limits $x = 0$ and $x = L$, there obtains

$$L + \frac{WL + \frac{1}{2}\,wL^2A}{EA}$$

for the total length of the bar after elongation.

Relations between the Force, or Strain applied to a bar, or rod, of a given cross section, and the length, &c., of the bar when rupture ensues; the strain being parallel to the direction of the length of the bar.

The principal results of experiments on the resistance offered by materials to rupture from a strain acting either to compress, or tear asunder the particles, thus calling into play the tenacity, or their resistance to compression, have been so fully given, that but little remains to be said here farther than to show the effect produced by the weight of the material itself, in modifying the strain arising from any external force; also the manner in which the form of the bar may be so modified as to make it most suitable to resist the strain arising from this external force and its own weight combined.

Suppose a bar of uniform cross section thoughout (Fig. B), the area of which is expressed by A, and its length A B by L, submitted to a strain arising from a weight W, suspended from B, and that of its own weight, and let w represent the unit of weight of the material of the bar. Representing by R, the *coefficient of rupture* of the given material,—that is the strain that would tear asunder a bar of the same material, the area of the cross section of which is unity,—then the resistance offered by the bar A B will be expressed by

$$R \times A.$$

The weight of the bar itself will be expressed by

It is evident that the greatest strain on the bar, arising from the combined action of W and its own weight, will be at the point A, and will therefore be expressed by

$$W + L A w;$$

and as the resistance offered by the tenacity of the bar must be equal to this strain, there obtains

$$R A = W + L A w$$

to express the required relations.

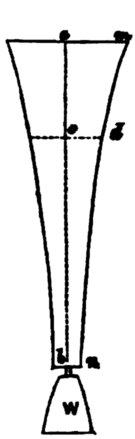


Fig. C.

To show the manner in which the form of a bar may be so modified that the area of its cross section, at any point, shall be just sufficient to resist the strain brought upon the material at that point; let a b (Fig. C) be such a bar the length of which is expressed by L; let any portion of the length, as b c, be expressed by x; let w represent the unit of weight of the material of the bar; W a weight suspended at its lower end; let the cross section of the bar, for example, at any point be a circle; let r designate the radius as c d of the cross section at the point c; r'' the radius a m of the top section; r' the radius b n of the bottom section; and $d\,x$ the length of an element of the bar.

The area of the cross section at c is πr^2, and as this area is supposed to vary from point to point the weight of a portion of the bar of which the length is x will be expressed by

$$w \int \pi r^2 \cdot d\,x;$$

and the strain upon the section at c, arising from this weight and that of the suspended weight W, will be expressed by

$$w \int \pi r^2 d\,x + W;$$

but as this strain must be just equal to the tenacity of the bar at c, and as $R \times \pi r^2$ represents its measure, there obtains

$$w \int \pi r^2 d\,x + W = R \times \pi r^2;$$

differentiating this expression, there results

$$w \pi r^2 d\,x = 2 R \pi r\,d\,r$$

hence

$$\frac{d\,r}{r} = \frac{w}{R} d\,x;$$

which integrated gives

$$\text{Log. } r = \frac{w}{R} x + C,$$

which shows that the curve n d m, cut from the bar by a plane through its centre, is a logarithmic curve.

Without passing from the preceding logarithmic expression to the equivalent numbers, equation

$$w\int \pi r^2\, dx + W = r \times \pi r'^2,$$

can be placed under the form

$$w\int A\, dx + W = R\, A$$

by making $\pi r^2 = A$; differentiating this as before, there results

$$w\, A\, dx = R\, d\, A;$$

and

$$\frac{d\, A}{A} = \frac{w}{R}\, dx.$$

Integrating r in this, between the limits r' and r'', and calling the respective areas at these points A' and A''; and also integrating x between the limits o and L, there obtains

$$\text{Log.}\, \frac{A''}{A'} = \frac{w}{R}\, L;$$

hence, passing to the equivalent numbers,

$$A'' = A' e^{\frac{w}{R} L;} \qquad \text{(B).}$$

but as the strain on the section A' is W, there obtains

$$A' R = W, \text{ and } A' = \frac{W}{R}$$

Substituting this value of A', in the preceding equation (B), there obtains

$$A'' = \frac{W}{R}\, e^{\frac{w}{R} L} \qquad \text{(C)}$$

for the value of the area at the upper end of the bar.

As the weight of any portion of the bar of the length x is expressed by

$$w\int A\, dx \qquad \text{(D)}$$

and the value for any variable section, at the distance x from the lower end, is found by substituting A for A'', and x for L in the equation (C) just preceding, the value of A so found substituted in the expression (D) gives

$$w\int \frac{W}{R}\, e^{\frac{w}{R} x}\, .\, dx$$

and this expression integrated between the limits $x = 0$ and $x = L$, becomes

$$w\int_0^L \frac{W}{R}\, e^{\frac{w}{R} x}\, .\, dx = W\left(e^{\frac{w}{R} L} - 1\right);$$

which is the value of the weight of the entire bar.

Relations between a force producing the rupture of a solid body by a cross strain on its fibres, and the resistances of compression and extension of the fibres produced by the action of the force.

The effect of a cross strain upon the fibres of a solid body, as a bar, or rod, caused by the action of a force, of which the line of direction is either perpendicular, or oblique to that of the fibres, is to deflect the solid, bringing a strain of extension upon the fibres towards the convex side, and one of compression on those towards the concave side of the solid. Separating the fibres which are elongated by the cross strain from those which are compressed, it is generally assumed that there exists a layer of fibres which is not affected by the cross strain, and which, on that account, has received from writers on this subject the name of the *neutral line*, or *neutral axis* of the solid. It is also generally assumed that when the deflection is inconsiderable, the elongations and diminutions in length of the extended and compressed fibres which are at equal distances on each side of the neutral axis are equal, and that these changes in the original lengths of the fibres are proportional to the distances of the fibres from the neutral axis. It therefore follows from what precedes, that so long as the elasticity of the fibres remains unimpaired under the action of the force, the resistances offered to elongation, or compression, will be proportional to the distances of the fibres from the neutral axis. In the state of a solid immediately bordering on rupture from the effects of a cross strain, it is probable that the elastic limits of the fibres which are farthest from the neutral line, both on the convex and concave sides, are exceeded before they are reached by fibres lying nearer to the neutral line, and that the resistances therefore are no longer strictly proportional to the distances of the fibres from the neutral axis. But as the hypothesis, that the elasticity of the fibres remains unimpaired up to the moment of rupture, approaches more nearly the actual state of the question than any other, it has been assumed by writers on this subject as the basis of the theory from which the formulas, showing the relations between the forces, are obtained, and a correction for the imperfection of the results thus arrived at has been sought, by comparing them with those obtained by direct experiment, and, by means of this comparison, deducing formulas more in accordance with the actual state of the case, and more suitable to practical applications.

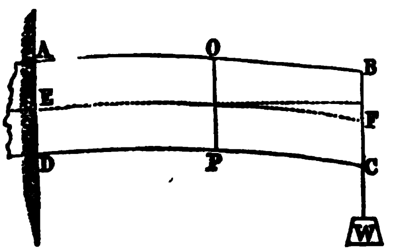


Fig. D.

Let A B C D (Fig. D) represent a longitudinal section of a bar firmly fastened at the end D, and acted upon by a force W, at the end B C, which tends to deflect the bar. Let E F be the position of the neutral axis, supposed to be known, and O P the line along which rupture is

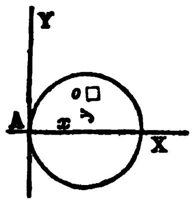


Fig. E.

about to take place from the effect of W. Let the area comprised within the curved line (Fig. E) be the cross section of the bar at OP. Let AX represent the position of the neutral axis on this cross section, and let this line, with the one AY drawn perpendicular to it at the point A, be taken as the coordinate axes to which all points of the cross section are referred.

Represent by

b, the breadth of the cross section estimated on AX;

d, the distance from AX and above it of the extreme fibre of the cross section, or the one which is most elongated;

d', the distance from AX of the one most compressed;

x and y, the coordinates of any fibre, as o;

R, the coefficient of rupture.

The area of any fibre will be expressed by $dx \times dy$; and the resistance which the extreme fibre from AX offers at the instant of rupture will be expressed by

$$R \times dx\, dy.$$

Now as the resistances offered by the fibres are proportional to their elongations, or compressions, and as these last are proportional to the distances of the fibres from the neutral axis, it follows that d being the distance of the extreme fibre from AX, and y that of any other fibre, as o, from the same, the resistance offered by o will be expressed by

$$\frac{y}{d} R \times dx\, dy.$$

The total resistance offered by all the fibres will therefore be expressed by the integral of this last expression, or by

$$\frac{R}{d}\int dx \int y\, dy$$

In like manner the total resistance offered by the compressed fibres is expressed by

$$\frac{R}{d'}\int dx \int y\, dy$$

Now assuming, at the instant of rupture, that the deflection of the solid is inconsiderable, and that the force W which causes it is perpendicular to the direction of the fibres, it follows that the conditions of equilibrium require that the algebraic sum of the forces in the direction of the fibres shall be equal to zero, and that the sum of the moments of all the forces with respect to the neutral line across the section at OP shall also be equal to zero.

The first of these conditions will be expressed by

$$\frac{R}{d}\int dx \int y\, dy - \frac{R}{d'}\int dx \int y\, dy = 0 \qquad \text{(A)}$$

as the resistance to elongation offered by any fibre at the distance y from the neutral line is $\frac{R}{d} dx\, dy\, y$, the moment of this resistance will be $\frac{R}{d} dx\, dy\, y^2$ and the sum of the moments of all the resistances to elongation will be expressed by

$$\frac{R}{d}\int dx \int y^2\, dy.$$

In like manner the sum of the moments of the resistances to compression

$$\frac{R}{d'}\int dx \int y^2\, dy.$$

Representing by z the perpendicular from OP upon the line of direction of W, the moment of W with respect to the neutral line across OP will be

$$Wz.$$

To express therefore the second condition of equilibrium there obtains

$$\frac{R}{d}\int dx \int y^2\, dy + \frac{R}{d'}\int dx \int y^2\, dy - Wz = o. \qquad (B)$$

Representing by $dA = dx\, dy$ the section of a fibre, or an element of the cross section corresponding to it, the eq. (A) will take the form

$$\frac{R}{d}\int_0^d y dA - \frac{R}{d'}\int_0^{d'} y dA$$

which expresses the condition that the neutral line AX (Fig. E) drawn through the section of rupture passes through its centre of gravity. When the neutral line therefore divides the section of rupture symmetrically, eq. (B) will take the form

$$2\frac{R}{d'}\int_0^b dx \int_0^{d'} y^2\, dy = Wz \qquad (C)$$

The sum of the two integrals in eq. (B), and the integral which forms the first member of eq. (C), have received the name of the *moment of rupture.* The integration being affected by the usual rules for integrals of this form, the limits of x being taken between $x = o$ and $x = b$, and y being either constant, or else a function of x, depending on the figure of the section of rupture, and its limits in the last case being $y = o$ and $y = f(x)$, the resulting equation will express the relations between the dimensions of the solid and the force producing rupture, when the value of R has been suitably ascertained by experiment.

Before proceeding farther it will be well to effect the integrations for the moment of rupture, as expressed in eq. (C) for some of the more usual cases where the cross section has uniform dimensions throughout the entire length of the solid.

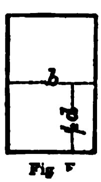


Fig. F

Taking the case of a rectangular cross section (Fig. F) the breadth of which is represented by b, and the depth by $d = 2\, d'$, the expression for the moment of

rupture becomes

$$2\frac{R}{\frac{1}{2}d}\int_0^b dx\int_0^{\frac{1}{2}d} y^2\,dy = R\frac{bd^2}{6}.$$

In the case of a circular cross section, representing by r the radius of the circle, the expression becomes

$$2\frac{R}{r}\int_{-r}^{r} dx\int_0^{y=\sqrt{r^2-x^2}} y^2\,dy = 2\frac{R}{r}\int_{-r}^{r} dx\,\tfrac{1}{3}\left(r^2-x^2\right)^{\frac{3}{2}} =$$

$$2\frac{R}{r}\times 2\int_0^{\frac{1}{2}\pi} dx\frac{r^4}{3}\sin.^4 . x = \frac{R\pi r^3}{4}$$

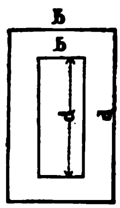


Fig. G.

In the case of a tube with a rectangular cross section (Fig. G), representing by b and d the breadth and depth of the exterior rectangle, and by b' and d' the like parts of the interior rectangle which forms the hollow of the tube, the moment of rupture will be

$$R\frac{bd^3 - b'd'^3}{6d};$$

and in that of a tube with a circular cross section, r and r' being the radii of the exterior and interior circles, the expression becomes

$$R\frac{\pi r^4 - \pi r'^4}{4r}.$$

In the case of a uniform cross section like (Fig. H), representing by b the entire breadth of the solid portion, and by d its depth: by b' the sum of the breadths of the rectangular voids on each side, and by d' their depth, the expression becomes, as in the case of a tube,

$$R\frac{bd^3 - b'd'^3}{6d}.$$

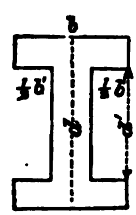


Fig. H

The foregoing examples will serve to show the method of obtaining the moment of rupture in all like cases of solid bars, or tubes with uniform cross sections where the neutral line divides the cross section symmetrically.

Resuming the general expression (C), which shows the relations between W and the other quantities, and applying it to the case of a beam with a rectangular cross section of uniform dimensions, the length of which AB, beyond the point where it is firmly fastened, is represented by l, the expression becomes

$$R\frac{bd^2}{6} = Wl; \qquad \text{(D)}$$

supposing the rupture to take place, as is evident from the eq., it will in such a case, at AD. From this eq. there obtains

$$W = R\frac{bd^2}{6l},$$

for the weight which the beam will bear at the moment of rupture.

If a beam is laid horizontally on two props, and a weight is placed upon it at the middle point between the props, the tendency of the beam to rupture will be at this point; and the strain upon the beam from W will evidently be the same as if the beam were firmly fixed at the middle point, and a force equal to $\frac{1}{2}$ W were applied at the point where the beam rests upon one of the props, and in a direction contrary to that of W. Representing by l the distance between the props, b the breadth, and d the depth of the rectangular cross section, d being estimated in the same direction as W, the preceding eq. (D) will take the form

$$R\frac{bd^2}{6} = \tfrac{1}{2}W \times \tfrac{1}{2}l = \tfrac{1}{4}Wl;$$

consequently

$$W = \tfrac{2}{3}R\frac{bd^2}{l}$$

It is from experiments made upon beams of a rectangular section, laid horizontally upon two props, and broken by a weight placed upon them at the middle point between the props, that the quantity R has been determined for the different kinds of materials. Having determined R from a number of such experiments the value of W can be determined by calculation when the quantities b, d, and l are known.

If instead of a weight acting at a single point, a beam of rectangular cross section is strained by a weight uniformly distributed over its top surface, the conditions of equilibrium from which the relations between the weight and the dimensions of the beam are established will be expressed as follows. Representing by w the weight on each unit of length of the beam, by dx (Fig. I) an elementary length of the solid at the distance x from the point where the solid is firmly fastened, and where the rupture will take place; then the weight distributed over the element dx will be wdx, and its moment with respect to the point of rupture will be $wdx \times x$. Calling the entire length of the solid l, the moment of the entire weight distributed over its length will be expressed by

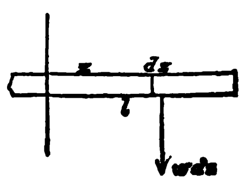


Fig. I.

$$\int_0^l w\,dx\,x;$$

and this, from the conditions of equilibrium, must be equal to the moment of rupture, or

$$R\frac{bd^2}{6} = \int_0^l w\,dz\,z = \frac{w\,l^2}{2} = \frac{w'}{2}\,l.$$

But wl expresses the entire weight distributed over the solid; therefore, from this last equation, it follows, that its effect upon the solid is the same as if half this weight were suspended from the end of the solid.

If the solid, besides supporting a weight w uniformly distributed over each unit of its length, has also a weight W suspended at its end, the conditions of equilibrium will be

$$R\frac{bd^2}{6} = Wl + \frac{wl^2}{2}$$

Solids of equal resistance.—This term is applied to solids in which the material is so distributed, with respect to the force, that the strain arising from it is the same at every point of the solid, and the tendency to rupture is therefore the same at all points. In a beam of a uniform rectangular cross section, for example, placed under the circumstances supposed in the preceding cases, the rupture will take place either at the end where the beam is firmly fixed, or at the middle point where the ends rest on props. As these are the weakest points, there will be an excess of strength at all other points, and therefore a waste of material. These considerations have led to an examination of forms by which this waste might be avoided. The change of form of the solid is usually effected by varying the dimensions of its longitudinal section made by a plane through its axis, the plane of section being either parallel to the line of direction of the force, or perpendicular to it, preserving either the breadth or depth of its cross section the same at all points.

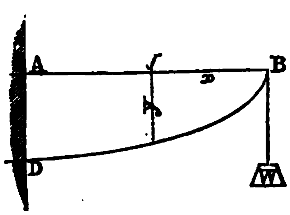


Fig. K.

Suppose a beam (Fig. K), of which the upper side is a plane surface, placed in a horizontal position, firmly fastened at one end, and strained by a weight W at the other; it is required to determine the form of its longitudinal section by a plane through its axis parallel to the direction of W, the breadth of the cross section being the same throughout.

Let l represent the length of the portion of the beam strained, b the uniform breadth of its cross section, d its depth at AD, where the beam is fastened, y the depth of the cross at any point, the distance of which from B, where W acts, is x.

To find the value of d there obtains from the preceding equations

$$R\frac{bd^2}{6} = Wl; \text{ and } d = \sqrt{\frac{6Wl}{Rb}};$$

and for the relations between y and x

$$R\frac{by^2}{6} = Wx;\ \text{hence}\ y^2 = \frac{6Wx}{Rb} = \frac{d^2x}{l};$$

A relation between y and x which expresses that the longitudinal section of the beam must be terminated at the bottom by a parabola, the vertex of which is at the point B. From the conditions of the problem a solid so shaped will offer an equal resistance at every point to the strain arising from the action of W.

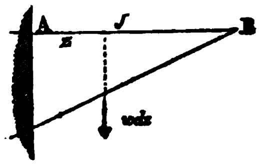


Fig. L.

Suppose, as in the last case, the top surface of the solid plane (Fig. L), its breadth uniform, and that the strain arises from a weight w uniformly distributed over each unit in length of the top surface.

Adopting the same notation as in the previous case there obtains, to find the value of d

$$R\frac{bd^2}{6} = \frac{wx^2}{2},\ \text{hence}\ d = l\sqrt{\frac{3w}{Rb}};$$

and to obtain the relations between x and y,

$$R\frac{by^2}{6} = \frac{wl^2}{2},\ \text{hence}\ y = \frac{dx}{l};$$

a relation that shows that the lower line of the longitudinal section is the right line BD.

Suppose a solid (Fig. M) with a rectangular cross section of uniform breadth throughout, the lower surface being plane, laid horizontally upon supports at its extremities, and strained by a weight placed at any point between the points of support.

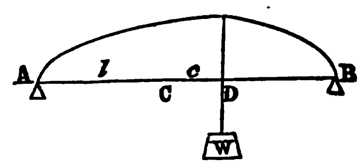


Fig. M.

Represent by b the uniform breadth of the cross section, by d its depth at the point where W acts, l half the horizontal distance between the supports, and c the distance between the point D, where the weight acts, and the point C, the middle point between the supports A and B. The solid will evidently be in the same state as if it were confined at the point D, and a weight equal to $W\frac{l-c}{2l}$ were applied at the point A, and in a contrary direction to W. The conditions of equilibrium therefore will be

$$R\frac{bd^2}{6} = \frac{l-c}{2l}(l+c)W = W\frac{l^2-c^2}{2l}$$

hence the depth of the beam at the point A is

$$d\sqrt{\frac{3W\,(l^2-c^2)}{R\,bl}}$$

It is evident from the preceding that, in order that the solid shall be equally strong throughout in this case, the top of it must be formed of the portions of two parabolas, the vertices of which are at A and B.

Were it required to ascertain the form of the longitudinal section, so that the solid should be equally strong to resist the action of the weight when placed at any point between the supports, the preceding equation of equilibrium will serve to establish the relation between the parts. For representing the depth of the solid at any point by y, and by x the corresponding distance from the middle points between the props to the point D, where the weight acts, the preceding equation will take the form

$$R\frac{by^2}{6} = W\,\frac{l^2-x^2}{2l}$$

which is the equation of an ellipse of which the vertices are at the points A and B, and of which the semi-conjugate is expressed by

$$y = \sqrt{\frac{3Wl}{Rb}}.$$

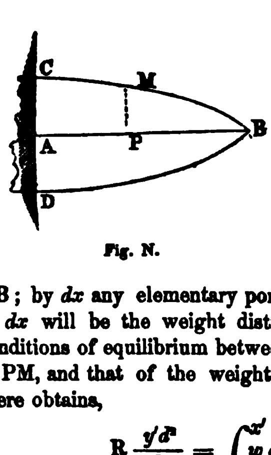


Fig. N.

Suppose a solid (Fig. N) with a uniform thickness d in the line of direction of the weight, but of variable breadth, subjected to a strain arising from a weight uniformly distributed along the centre line AB of the solid.

Representing by y any ordinate PM of the curve which bounds the top surface of the solid, and by x' its abscissa PB; by w the weight borne by each linear unit of AB; by dx any elementary portion of AB, at the distance x from B; then $w\ dx$ will be the weight distributed over the element dx. To express the conditions of equilibrium between the moment of rupture of the cross section at PM, and that of the weight of any portion of the solid of the length x, there obtains,

$$R\,\frac{y'd^2}{6} = \int_0^{x'} w\,dx\,(x'-x) = \tfrac{1}{2}\,w\,x\,(2x'-x).$$

Representing by $l =$ AB the length of the solid from DC where it is firmly fixed, and by $b =$ AC, the foregoing expression becomes

$$R\,\frac{bd^2}{6} = \tfrac{1}{2}wl^2;\ \text{hence}\ b = \frac{3wl^2}{Rd^2}.$$

Since for the cross section at AC, $x = x' = l$, and $y' = b$.

The preceding expressions show that the curve CMB is a parabola, of which C is the vertex, and the line CA the axis.

From the preceding examples, the relations between the moment of rupture and the strain caused by a force acting in a given manner on a solid of any form of cross section, whether constant or variable, may be established when the dimensions of the cross section are connected by any geometrical law. In the most important cases in structures, these relations are usually expressed in the most simple terms for convenient arithmetical calculation, the constant, represented by R in the preceding equations, being determined from experiments made on the solids of the form to which the formulas are applicable. Examples of formulas derived in this manner, and adapted to arithmetical calculation, are given in Art. 320, page 92, and at the end of Note A on tubular bridges.

A large number of experiments have been made to ascertain the value of R, by submitting solids of a rectangular cross section to cross strains producing rupture. As might have been anticipated, the values of R so determined vary considerably. The mean value for timber is usually taken at 12,000, and that for cast iron at 40,000. In practical applications, the value for timber is reduced to the one-tenth, or 1200, and that for cast iron to the fourth, or 10,000, of that determined by experiment, when the formulas are used to fix the strain to which the material can be subjected in safety in the ordinary cases of structures.

Manner of estimating the strains on frames of straight beams of rectangular cross section, and the relations between the strain on each piece and its dimensions.

The problems presented under this head consist of two parts: the first, to find the directions and intensities of the strains on the component parts of a frame, composed of straight beams with rectangular cross sections, arising from a given strain acting at any assumed point of the frame; the second, so to proportion the dimensions of each part that it shall resist, without danger of rupture, the strain thrown upon it. The first part depends for its solution on the two fundamental propositions of statics; the parallellogram of forces and the theorem of moments. The second is but an application of the preceding formulas in this note.

Solid Built Beams.—The resistance offered by this class of beams to a cross strain will depend on the manner in which the pieces are placed together, and the connexion between their surfaces of contact. In beams like (Fig. 57), p. 171, art. 502, in which each course is formed of two or more beams abutting end to end, and all the courses are firmly secured to each other, so that the surfaces in contact cannot slide on each other, we may regard the strength of the beam, supposing the courses of equal thickness, as equal to that of a solid beam having a depth equal to that of the built beam diminished by the thickness of one course.

Where each course consists of a single beam, and the whole are united so as to prevent sliding (Figs. 59, &c.), then the resistance offered may be regarded the same as that of a solid beam of equal depth.

Adopting the same notation, as in the preceding part of the note, for beams of rectangular cross section, the formulas for a solid beam, on pp. 386–7–8, may

be used in these cases of built beams, under like circumstances of the position of the beam and the point of application and direction of the strain.

The formula at the bottom of p. 389 is applicable to this class when submitted to a strain acting at any point between the centre of the beam and its points of support.

In all such cases, however, the liability of the beam to break at one point rather than another, owing to the manner in which it is built, must be carefully considered, and a suitable modification of the formula be made, if requisite. The quantity R also, which enters into the formulas, and which for solid timber it is stated should be reduced to 1200 lbs. in cases of practice, may be further reduced one-third in such cases, to be on the side of safety.

Open Built Beams.—In this class of beams (Fig. 68), p. 172, in which the breadth and depth of the solid parts at top and bottom is the same, the relations between the weight that the beam will bear with safety applied at the centre point between the supports, and the other quantities will be

$$W = \tfrac{2}{3} R' \frac{b d^3 - b d'^3}{d l}.$$

in which R′ is the reduced value of R.

Solid Beams.—From the formula (D), p. 386, by substituting R′ for R, there obtains

$$R' = 6 \frac{W l}{b d^2}$$

which gives the relations which must exist between the weight and dimensions of the beam, in order that the strain on the unit of surface of the fibres shall not exceed the quantity R′. If, in addition to the strain arising from W applied perpendicularly to the axis of the beam, there was another W′ acting parallel to the axis, so as either to compress or extend the fibres, this would cause a strain on the unit of surface of the cross section expressed by

$$\frac{W'}{b d}.$$

In order, therefore, that the total strain arising from W and W′, applied as here supposed, shall not exceed that which the unit of cross section can be submitted to with safety, there must obtain

$$R' = 6 \frac{W l}{b d^2} + \frac{W'}{b d}$$

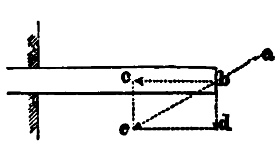


Fig. O.

If we now suppose a beam (Fig. O), fastened at one extremity, to be subjected to a strain applied at the other obliquely to the axis, we can regard the oblique strain as replaced by its two components, the one perpendicular the other parallel to the axis of the beam. Representing the perpendicular component by W, and the parallel one by W′, the

same relations will evidently obtain between these components and the other quantities as in the preceding case, in order that the strain on the unit of area of the cross section shall not exceed R′.

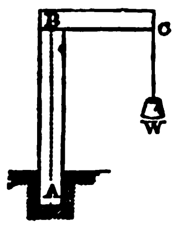


Fig. P.

When a pressure, or a force of extension is applied parallel to the axis of a beam (Fig. P.), but not in the same line with it, its effects will be to compress, or extend the beam in the direction of the axis, and to produce a cross strain on the fibres, owing to the tendency to bend the beam.

Supposing a vertical beam A B, fastened at the point A, and a weight W applied at the extremity of another beam B C, firmly connected with the first, and perpendicular to its axis. The compression of A B, in the direction of the axis will be equal to the entire weight W, and that on the unit of area will be

$$\frac{W}{b\,d};$$

in which b is the breadth, and d the thickness of A B, the latter estimated in the plane through the axis in which the force acts.

Representing by h the horizontal distance B C, from the axis at which W acts, its moment will be equal to the moment of rupture of the fibres, or

$$W\,h = \tfrac{1}{6}R'\,b\,d^2$$

In order, then, that the strain on the unit of area shall not exceed the prescribed limit there obtains

$$R' = 6\frac{W h}{b\,d^2} + \frac{W}{b\,d}$$

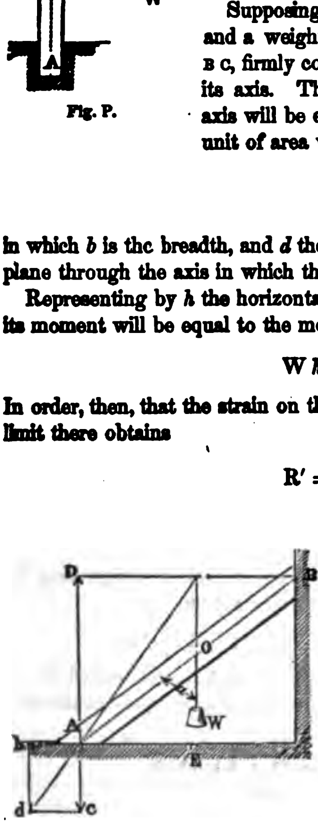


Fig. Q.

Let the case now be supposed of an inclined beam, A B, which rests on a horizontal surface A C, whilst the upper end lies against a vertical surface B C, the beam having a weight W, suspended from its middle point O.

Represent by l the length A B, of the beam, and by a, the angle between its axis, and the vertical at O.

Leaving out of consideration the friction between the foot of the beam and the horizontal surface on which it rests, it is evident that the reaction of the vertical surface against the upper end would cause the beam to slide along A C, and that to prevent this, the end, A, must be confined. The tendency of W, therefore, will be to turn the beam around the point A, and this will be counteracted

by the reaction of B, acting horizontally. Designating this force of reaction at B, by P, there obtains from the theorem of moments,

$$P \times AD = W \times AE;$$

or, substituting for AD and AE their respective values, l cos. a, and $\frac{1}{2}$ l sin. a.

$$P = \tfrac{1}{2} W \tan. a.$$

By confining the foot of the beam, an equal horizontal force is called into play at A, whilst the total weight, W, is supported at the same point. The total pressure at A will, therefore, be the resultant of these two forces, which are perpendicular to each other, and will be expressed by

$$\sqrt{W^2 + \tfrac{1}{4} W^2 \tan.^2 a} = W \sqrt{1 + \tfrac{1}{4} \tan.^2 a}.$$

Or representing by A b and A c the directions and intensities of the two forces, W, and $\frac{1}{2}$ W tan. a, the diagonal, A d, of the rectangle will represent the direction and intensity of the resultant.

Having thus found the magnitude, direction, and point of application of the two forces, there is next to be considered the strains to which they subject the fibres. To do this, the beam may be regarded as confined at the point o, the lower portion, o A, being acted upon by the two forces, A b and A c, at the point A; the upper portion, o B, by a horizontal force equal to A b, at the point B Decomposing the force A b$=\frac{1}{2}$ W tan. a, perpendicular and parallel to the axis A o, the components will be represented respectively by

$$\tfrac{1}{2} W \tan. a \cos. a; \text{ and } \tfrac{1}{2} W \tan. a \sin. a.$$

The components of W in the same directions are

$$W \sin. a; \text{ and } W \cos. a.$$

It will be observed that the components perpendicular to the axis, and which produce a cross strain, act in opposite directions with an intensity equal to their difference expressed by

$$W \sin. a - \tfrac{1}{2} W \tan. a \cos. a = \tfrac{1}{2} W \sin. a.$$

The components parallel to the axis act in the same direction, compressing the fibres with an intensity equal to their sum, and expressed by

$$W \cos. a + \tfrac{1}{2} W \tan. a \sin. a = W \cos. a (1 + \tfrac{1}{2} \tan.^2 a).$$

Representing by b the breadth, and d the depth, of the beam estimated in the plane of the forces, there obtains, as in the preceding case, to represent the limit of the strain on the unit of area

$$R' = \tfrac{3}{2} \frac{W \sin. a\, l}{b d^2} + \frac{W \cos. a. (1 + \tfrac{1}{2} \tan.^2 a)}{b d}.$$

Considering next the upper half o B, which is acted on only by the horizontal force at B, equal to $\frac{1}{2}$ W tan. a; the components of this force, perpendicular and parallel to the axis, are

$$\tfrac{1}{2} W \tan. a \cos. a; \text{ and } \tfrac{1}{2} W \tan. a. \sin. a.$$

The perpendicular component producing a cross strain, and the parallel one a strain of compression. To express the limit of the strain on the unit of area for this portion, there obtains

$$R' = \tfrac{3}{2}\frac{W \sin. a\, l}{b d^2} + \tfrac{1}{2}\frac{W \tan. a. \sin. a}{b d}.$$

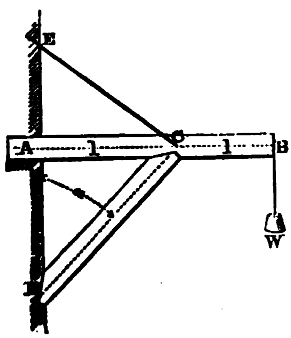


Fig. R.

To prevent the flexure of a horizontal beam, as A B (Fig. R), confined at one end, and sustaining a weight at the other, an inclined strut D C is placed beneath it, abutting against some fixed point as D, and against the beam at some point between A and B; or else a tie is used leading from a point C, to some fixed point, as E above.

Represent by l the distance A C, by l' that C B; by a the angle that the axis of the strut makes with the vertical.

As the point C is fixed, the weight W, acting at B, will tend to turn the beam around this point, and this will call into play a vertical force at the point A which, from the theorem of moments, is expressed by

$$W\frac{l'}{l};$$

the fixed point C, therefore, sustains a vertical effort which is equal to the sum of this force and W, and is expressed by

$$W + W\frac{l'}{l} = W\frac{l + l'}{l}.$$

As the point C is supported by the strut, the vertical force at C may be decomposed into components in the direction of the axes of the strut and the beam. That along the strut will be expressed by

$$W\,\frac{l + l'}{l \cos. a},$$

and will compress it in the direction C D. The one along the axis of the beam is

$$W\frac{l + l'}{l}\tan. a.$$

and will produce a strain of extension on the part A C of the beam. This portion A C is, therefore, subjected to a cross strain, which tends to rupture it at C, from the force $W\frac{l'}{l}$ at the point A, and to extension from the force acting along its axis. There obtains, therefore, to express the limit of the strain on the unit of area

$$R' = \frac{6\,W\,l'}{b\,d^2} + \frac{W\,(l + l')\,\tan.\,a}{l.\;b\,d}.$$

For the strut there obtains,

$$R' = \frac{W\,(l + l')}{l\cos.\,a\,b'\,d'}$$

b' and d' being the two sides of its rectangular cross section.

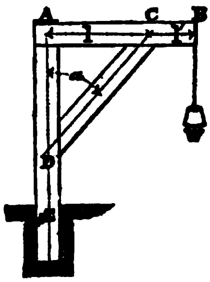


Fig. S.

If the beam A B (Fig. S) is supported by a vertical post A E firmly fastened at A, the strains on the strut and the part A C will be estimated as in the case just examined. As to the strains on the post, it will be observed that the force acting along the strut, and which is represented by

$$W\frac{l + l'}{l\cos.\,a},$$

will be transmitted to the point D. This will be equivalent to a horizontal force represented by

$$W\frac{l + l'}{l}\tan.\,a;$$

and a vertical one represented by

$$W\frac{l + l'}{l}.$$

acting at C.

From the connexion formed by the strut between the horizontal beam and the post, the effect of these two components will be to cause a pressure on the part D E of the post, which will be equal to W; and to produce a cross strain by the horizontal force, the moment of this force being expressed by

$$W\frac{l + l'}{l}\tan.\,a \times \frac{l}{\tan.\,a} = W\,(l + l').$$

To express, therefore, the limit of the strain on the unit of area of this part D E, there obtains

$$R' = \frac{6\,W\,(l + l')}{b\,d^2} + \frac{W}{b\,d}\;(X).$$

In like manner, the part A D will be subjected to a cross strain from the horizontal force above-mentioned, which tends to cause rupture at the point D, and to a strain of extension, acting upwards along A D, from a vertical force at A expressed by

$$W\frac{l'}{l}.$$

The limit of the strain, therefore, on this portion will be

$$R' = \frac{6\,W\,(l + l')}{b\,d^2} + \frac{W\,l'}{l \times b\,d}.\;(Y).$$

By comparing the two expressions (X) and (Y), it will be seen that they will be equal when $l=l'$, in which case the post will have an equal tendency to rupture at D, or at any point of the portion D E. When $l < l'$ then the tendency to rupture is rather in the part D E, than at D.

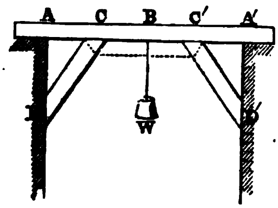


Fig. R'.

The discussion of the strains on (Figs. R and S) naturally leads to a consideration of combinations of beams represented in (Figs. R' and S').

In combinations of this kind, the simplest and safest plan consists in supposing the frame resolved into parts, such that either alone will be strong enough for the object in view, and to regard their combination as affording an excess of strength sufficient to insure perfect safety from rupture. In (Fig. R'), which consists of a horizontal beam, resting on the points of support A, A', and supported at the intermediate points C, C', by struts D C, D' C', firmly connected with the beam, and at the fixed points, D, D'; the beam, in the first place, may be regarded as alone supporting the weight, W. at its middle point B, and the area of its cross section be so determined, that the strain on the unit of area shall not be greater than the limit fixed on. Having calculated the dimensions of the horizontal beam in this manner, the weight may, in the second place, be regarded as supported by the portion C C' of the beam, and the two struts D C and D' C', in which case the strains on these parts, and their limits on the unit of area of their cross section will be determined by considering, that at the points C and C' a vertical force ½ W is acting, the components of which in the direction C D and C B are respectively

$$\frac{W}{2 \cos. a}; \text{ and } \tfrac{1}{2} W \tan. a.$$

Representing by b' and d' the sides of the cross section of the strut, there obtains to express the limit of the strain for it

$$R' = \frac{W}{2 \cos. a\, b' d'}.$$

For the portion of the beam C C', it may be regarded as confined at its middle point, where W acts, and subjected to the two forces ½ W, and ½ W tan. a, the first producing a cross strain, and the second one of compression in the direction of its axis. Representing the distance B C therefore by l', there obtains to express the limit

$$R' = \frac{6\, W\, l'}{2\, b\, d^2} + \frac{\tfrac{1}{2} W \tan. a}{b\, d}. \quad (X')$$

Representing by l the distance A C, there obtains to express the limit, when the beam A A' alone sustains the weight,

$$R' = \frac{6\,W\,(l + l')}{2\,b\,d^2}. \quad (Y'.)$$

Now, comparing the two values of R′ in the expressions (X′) and (Y′), it will be seen that the combination of the struts and the piece C C′ alone will be stronger than the beam A A′ alone, when

$$\tan. a < \frac{6\,l'}{d}.$$

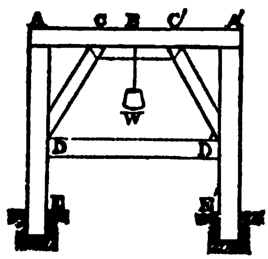


Fig. 8′.

In like manner in combinations like (Fig. 8′). in which the points of support are two posts, A E, and A′ E′, firmly fastened at E and E′, we may regard, in the first place, the beam A A and the two posts as alone sustaining the entire weight W, applied at B, the centre point of A A′, and ascertain the limits of the strains to which these pieces can be respectively subjected. Then the weight may be considered as sustained by the portion C C alone, the two struts, C D, and C′ D′, and the posts. Having ascertained, as in (Fig. 8), the strains on these parts, and the limits to which they can be subjected, if it be found that either of these combinations alone will be sufficiently strong, then will the entire combination have an excess of strength.

As the beam A A′ is firmly connected with the posts at A and A′, a strain of extension will be thrown on the portion A C, from the pressure at D acting through the strut C D, which pressure is represented by $\frac{W}{2 \cos. a}$. This again may be regarded as equivalent to a horizontal and a vertical force respectively represented by

$$\frac{W \tan. a}{2}, \text{ and } \frac{W}{2}.$$

Representing by h, and h' the distance E D, and E A, the horizontal force will cause a strain at A, acting in the direction A C to extend this part represented by

$$\frac{W\,h' \tan. a}{2\,(h + h')},$$

and one at the fixed point E represented by

$$\frac{W\,h \tan. a}{2\,(h + h')}.$$

These two components of the horizontal force at D will cause a cross strain on the post. We may, therefore, regard the post as confined at the point D, and the portions on each side of D subjected to a cross strain from the horizontal components, the moments of which components will be the same, and respectively represented by

$$\frac{W\, h\, h'\, \tan. a}{2\,(h + h')};$$

and to a strain in the direction of the axis represented by $\frac{W}{2}$. The limit therefore, of the strain to which the post can be subjected will be

$$R' = \frac{W}{2\, b'\, d'} + \frac{6\, W\, h\, h'\, \tan. a}{2\, b'\, d'^2\,(h + h')}$$

in which b' and d' are the sides of the rectangular cross section of the post.

Straining and Tie Beams.—If the struts C D, C′ D′ (Figs. R′, S′), instead of being connected with the beam A A′, abutted against a straining beam placed beneath the portion C C′, as shown by the dotted line, then the horizontal strain on the beam A A′, from the action of the struts, would be borne by the straining beam alone. This portion of the frame, composed of this beam and the portion C C′ of the beam A A′, may be regarded as a single beam submitted to a cross strain from the weight W, and to a strain of compression on the straining beams alone from the horizontal component of the pressure at the point C or C′, and the relations between the limits of the strain on the unit of area and the dimensions of the beams be found as in the previous cases.

If the struts, instead of abutting at D and D′ against the wall, or posts, were confined by a tie beam shown by the dotted lines D D′, this beam would relieve these points from the horizontal pressure, and would itself be subjected to a strain of extension equal in amount to the horizontal strain on the straining beam.

In the preceding cases, the frame has been considered as subjected to the action of a strain acting at one point alone; if, in addition to this, the beam A A′ was subjected to a strain uniformly distributed along it, the vertical pressures at C C′ and A A′ would have to be increased. Representing by w the weight uniformly distributed on the unit of length of A A′, the total weight on the portion A C will be represented by $w\, l$, and that on the portion B C by $w\, l'$; the vertical pressure at C arising from these two will, therefore, be represented by

$$\tfrac{1}{2}\, w\, l + w\, l',$$

and this must be added to the vertical component of W at the same point, in all the preceding formulas, to make them applicable to this case.

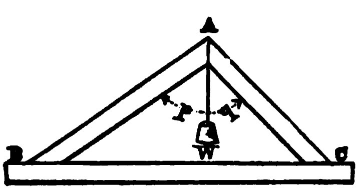


Fig. T

Combinations, like (Fig. T), composed of two inclined pieces, A C and B C, abutting against each other at A, and confined at B and C, either by being inserted into a horizontal tie beam, or abutting against fixed points, may be arranged either for sustaining a vertical strain at the point A, as that arising from a weight suspended at A; or, as in

he case of the rafters of a roof truss, to sustain a pressure uniformly listributed over the two inclined pieces.

Representing by p and q, the angles between the inclined pieces, and the vertical through A, the components of W, in the directions A B and A C, will be respectively represented by

$$W \frac{\sin. q}{\sin. (p + q)}; \quad W \frac{\sin. p}{\sin. (p + q)};$$

and the horizontal pressure at A, which is the same as the horizontal strain at the points B and C, is represented by

$$W \frac{\sin. p \sin. q}{\sin. (p + q)}.$$

Each of tnese beams may, therefore, be regarded as confined at their lower points, and subjected at their upper ones to the strains in the direction of their axes just determined; and from these the relations between the limits of the strain on the unit of area and the dimensions of the beams can be determined as in the preceding examples.

When the angle p is equal to q, the strains in the direction of each beam will be expressed by

$$\frac{W}{2 \cos. p};$$

and the horizontal strain by

$$\tfrac{1}{2} W \tan. p.$$

Were the beams in this last case, instead of supporting a vertical pressure at tne point A, each subjected to a vertical strain applied at any point between A and the foot of each beam, it is obvious that each would be in the same condition as the one (Fig. Q), and that the horizontal strains at the points A, B, and C, those in the direction of the axes of each beam, and the total pressure at B and C, would be found as in (Fig. Q); and from these the relations between the dimensions of the beams and the limit of the strain on the unit of area be in like manner determined.

The applications of the preceding problems to the analogous cases of frames composed of rigid materials, as timber and iron, will be readily seen on a comparison of the forms in Art. 507, and the following, with those which have just been the subjects of examination. The main difficulty in each case will be in determining those strains both in intensity and direction, which arise from the reciprocal action of the component parts of the frame, and this will be most easily overcome by supposing the parts pressed against removed, and their resistance replaced by forces acting in the same directions as the resistances; as, fo example, in the case of (Fig. Q), where a horizontal force at B might be made to replace the resistance of the wall against which the beam rests, &c.

In all cases, moreover, where a strict equilibrium does not obtain, either l

the strains being transmitted to fixed points, or by equal counteracting forces, the stability of the framing will depend on the joints, or connexions of the beams; and wherever there is a tendency to the rotation of any one of the beams around a joint, it must be prevented by the introduction of a strut or tie, so placed as to hold the beam, liable to this movement, in a fixed position.

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